

2<sup>nd</sup> Advanced Training Course on  
“Illicit trafficking and Radiological Consequences” with Nucleonica  
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# Gamma Spectrum Generator

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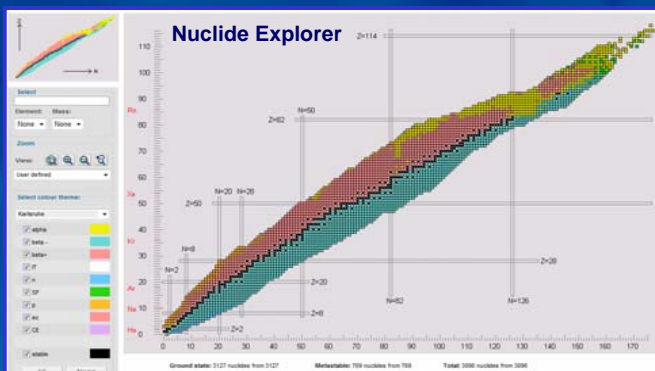
*European Commission, Joint Research Centre  
Institute for Transuranium Elements, Karlsruhe, Germany*

nucleonica



[www.nucleonica.net](http://www.nucleonica.net)

# Nucleonica's unique feature: Web-based Nuclear Science Applications



**Mass Activity Calculator**  
55 Cesium

Current Chart: Karlsruhe

Element: Cs, Mass: 137, Mixture selector

Unit: Grams, Quantity: 1, Update

Unit	Quantity
Grams	1.000
Becquerel	3.216e+12
Curies	86.93
Number of Atoms	4.399e+21
Moles	7.304e-3
$\mu\text{Sv/h}$ (vacuum)	0.7590

at 100 cm distance, Threshold energy ( $\gamma$  & X rays) = 15 keV

**Decay Engine**  
84 Polonium

Actual Chart: Karlsruhe

Element: Po, Mass: 218, Nuclide Mixture Selector

Decay Engine Options

Quantity: Grams, 1, Accuracy Factor: 1E-02

Time: Minutes, 8.10E+01, Number of timesteps: 40, Number of chains: 1

Start, Start in background, Reset, Show details, Create Nuclide Mixture

Parent-Daughter	Half life	$\lambda$ (atoms)	$\lambda$ (Bq)	$\lambda$ (dpm)	$\lambda$ (Bq)	$\lambda$ (dpm)
84 Po218	3.1 m	3.72E-13	1.35E-08	1.39E-11	0	0
82 Pb214	26.8 m	3.84E-20	1.37E-01	1.66E-17	2.32E-07	2.32E-07
83 Bi214	19.9 m	5.47E-20	1.94E-01	3.17E-17	3.49E-07	3.49E-07
84 Po214	1.6E2 $\mu$ s	7.50E-13	2.65E-08	3.17E-17	0	0
82 Pb210	22.17 y	1.83E-21	6.36E-01	1.81E-12	1.25E-06	1.25E-06
83 Bi210	5.01 d	3.97E-15	1.38E-06	6.35E-09	8.26E-06	8.26E-06
84 Po210	1.4E2 d	9.99E-12	3.13E-09	5.21E-05	6.25E-01	6.25E-01
82 Pb206 Stable	stable	5.39E-08	1.84E-13	0	0	0
Total:		2.78E-21	9.69E-01	9.01E-17	5.94E-07	5.94E-07

... web driven nuclear science

## Application Centre

- » Mass Activity Calculator
- » Decay Engine
- » Dosimetry & Shielding
- » Range & Stopping Power
- » webKORIGEN
- » Universal Nuclide Chart
- » Transport & Packaging
- » Nuclide mixtures
- » Nucleonica Scripting
- » Library creation for 3rd party software
- » Gamma Spectrum Generator (IE only)
- » easy Monte Carlo (IE only)
- » Cambio file Converter
- » Extended Graph Module

## Data Centre

- » Physical Constants
- » Nuclide Reference Data
- » Nuclide Derived Data

**Cambio File Converter**

Convert a file, Manage files, Spectrum, Diagnostics, About Cambio

Step 1: Please select a file to be converted.

Step 2: Choose the format to convert to (Instrument / 3rd party software).

Step 3: Convert the file using Cambio.

Step 4: Download the converted file.

Uploaded file: C:\Berlivo\NDA\Measurements\GSG\DU\_BRS\_Spectral\Cs\_137\_punk1\_500\_20090429.CNF

Converted file: C:\Nucleonica\PrecompiledWebApplication\Cambio\CambioFolders\8a70ffa4-6d2a-4056-a78e-80d7cbd320ab\Cs\_137

**Gamma Spectrum Generator**  
27 Cobalt

Actual chart: Karlsruhe

Element: Co, Mass: 60, Nuclide Mixture Selector

Quantity: Becquerel, 1000000, Reference point: Measurement start

Measurement setup: Measurement time: sec, 1000, Start

Current configuration: Nal, L x D = 3 in x 3 in (default)

Dimensions in mm: Source, Filter, Crystal, Crystal diameter, Crystal length, Source to Detector distance, 250.0, 76.2, 76.2, ☐ Show more settings

**easyMonteCarlo**  
63 Europium

Actual chart: Karlsruhe

Element: Eu, Mass: 152, Mixture selector

Activity (Bq): 1E+10

Shield: Compound, Paraffin, Detector: Particle flux, Dose rate

Start, Stop, Resume, Pass spectrum to GSG

Geometry: Source Options, Results, Input Parameters, Service Output

Source Diameter: 10, Shield: 50, Source to shield: 40, Source to Detector: 100, Detector

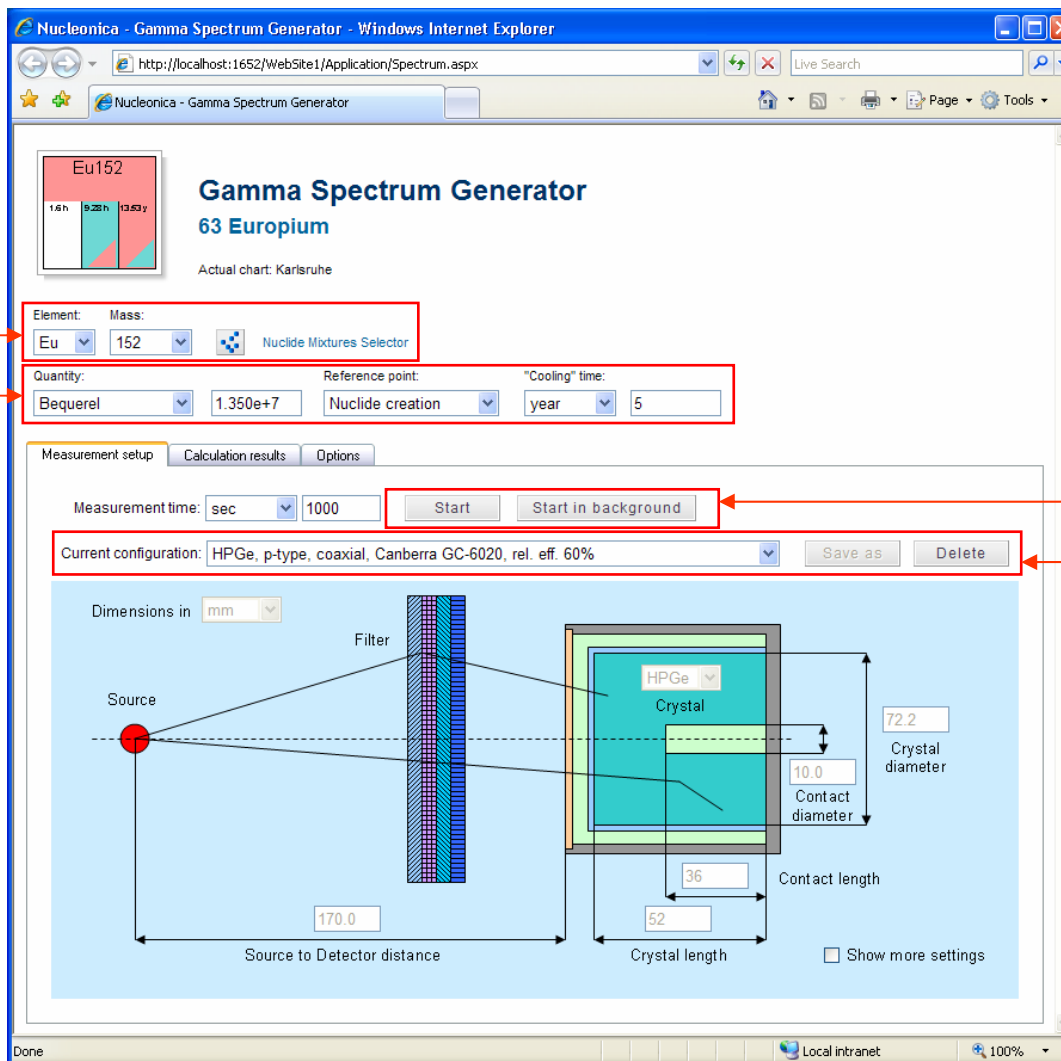
## Outline

- **GSG Version 1** (*point-like slightly shielded sources*)
  - Introduction to GSG features
  - Spectrum modeling examples
  - Experimental validation
- **GSG Version 2** (*extended & heavily shielded sources*)
  - Highlights of new features
  - Introduction to EMC & coupled EMC-GSG simulations
  - Experimental validation
- **Exercises**

## Features implemented: Measurement setup

An arbitrary individual nuclide or a pre-defined mixture of nuclides can be selected as a radiation source

The quantity (activity, mass or number of atoms) of a nuclide or a mixture can be specified either at the moment of its production or at the spectrum measurement starting point of time. In the former case controls for specifying duration of a source cooling time interval become available.



**Nucleonica - Gamma Spectrum Generator**  
63 Europium  
Actual chart: Karlsruhe

Element: Eu Mass: 152 Nuclide Mixtures Selector

Quantity: Bequerel 1.350e+7 Reference point: Nuclide creation "Cooling" time: year 5

Measurement setup Calculation results Options

Measurement time: sec 1000 Start Start in background

Current configuration: HPGe, p-type, coaxial, Canberra GC-6020, rel. eff. 60% Save as Delete

Dimensions in mm

Source to Detector distance: 170.0

Filter

HPGe Crystal

Crystal diameter: 72.2

Contact diameter: 10.0

Contact length: 36

Crystal length: 52

Show more settings

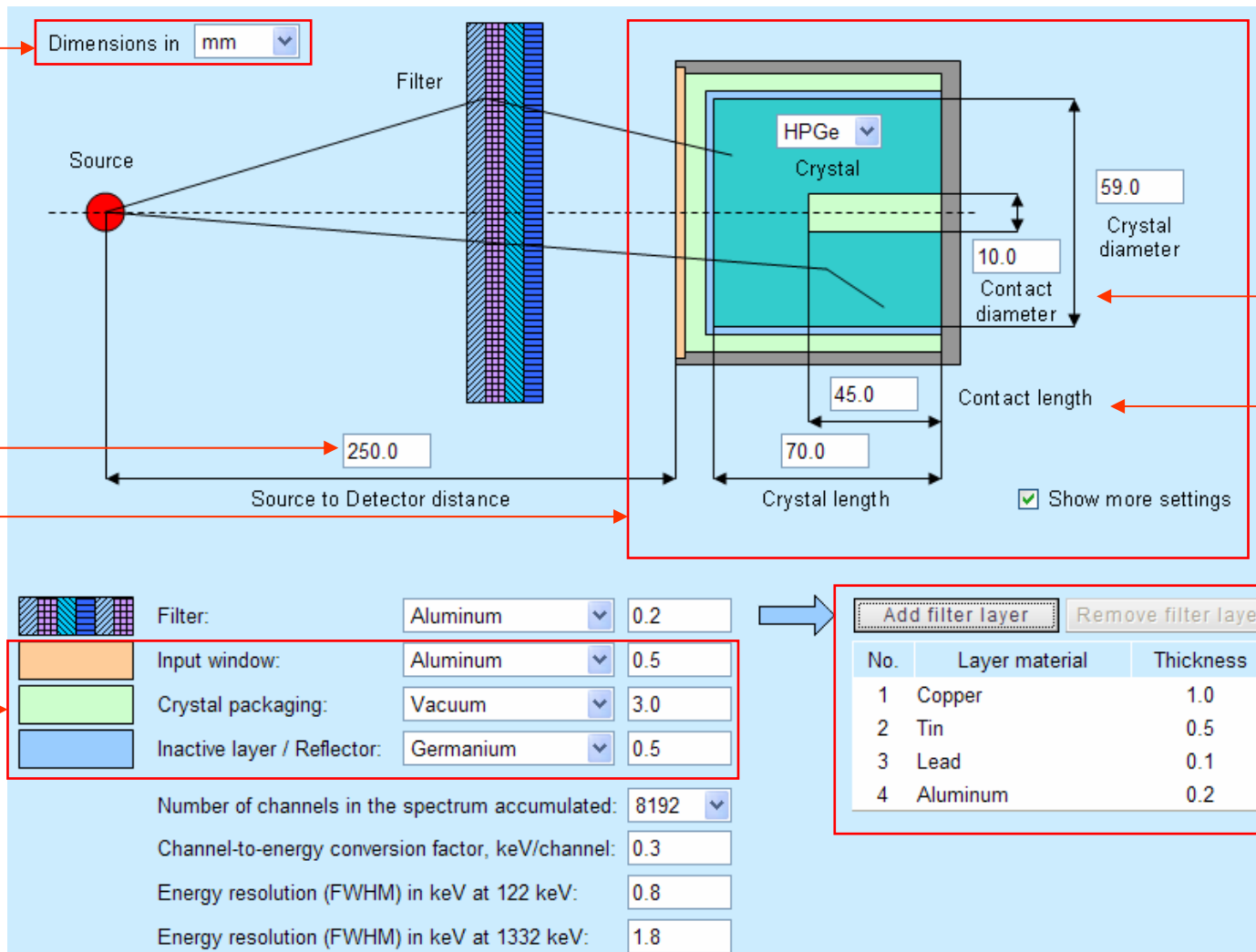
Calculations can be started on-line or in a background mode

A suitable  $\gamma$ -spectrometer can be chosen from 6 pre-defined configurations, which include 2 coaxial HPGe (50% and 150%) detectors, low-energy (LEGe) and broad-energy (BEGe) HPGe detectors, and 2 NaI detectors ( $\varnothing 3'' \times 3''$  and  $\varnothing 2'' \times 1''$ ). In addition, user's specific configurations can be managed.

## Features implemented: Measurement setup

Dimensions can be entered in “mm”, “cm” or “inch” units

The configurable parameters include the source-to-detector distance, as well as dimensions and materials of the detector construction elements.



Dimensions in

Source

Filter

HPGe

Crystal

59.0

Crystal diameter

10.0

Contact diameter

45.0

Contact length




70.0

Crystal length

250.0

Source to Detector distance

☒ Show more settings

	Filter:	Material	Thickness
	Input window:	Aluminum	0.2
	Crystal packaging:	Vacuum	3.0
	Inactive layer / Reflector:	Germanium	0.5

Number of channels in the spectrum accumulated:

Channel-to-energy conversion factor, keV/channel:

Energy resolution (FWHM) in keV at 122 keV:

Energy resolution (FWHM) in keV at 1332 keV:

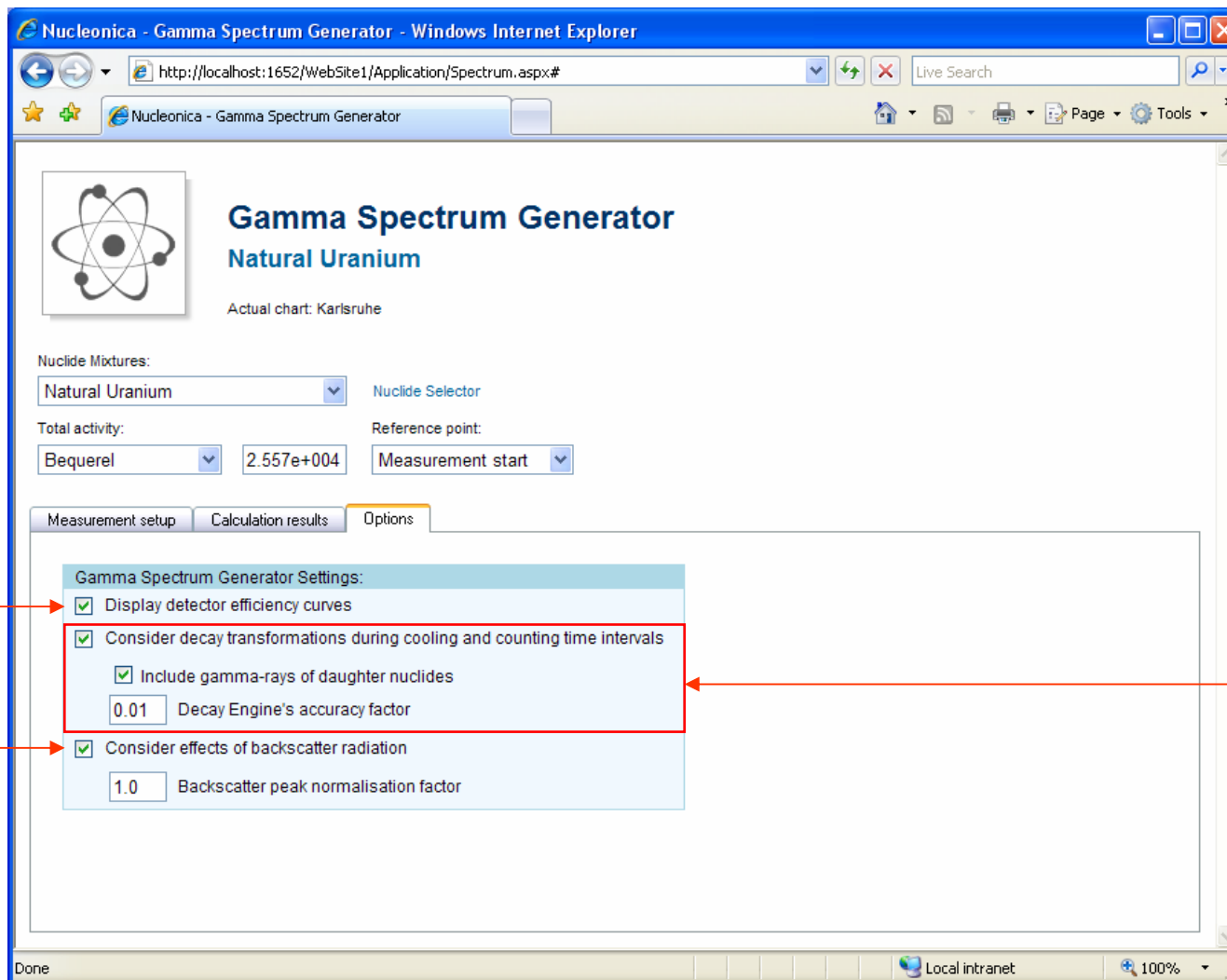
Add filter layer Remove filter layer

No.	Layer material	Thickness
1	Copper	1.0
2	Tin	0.5
3	Lead	0.1
4	Aluminum	0.2

The dimensions of a cylindrical contact at the rear side of the crystal (a construction feature of conventional coaxial HPGe detectors) can be specified

Up to 6 additional absorbing filters made of Al, Cu, Fe, Pb, Sn, or polyethylene can be placed between source and detector


## Features implemented: Options



Nucleonica - Gamma Spectrum Generator - Windows Internet Explorer

http://localhost:1652/WebSite1/Application/Spectrum.aspx#

Nucleonica - Gamma Spectrum Generator

 **Gamma Spectrum Generator**  
Natural Uranium

Actual chart: Karlsruhe

Nuclide Mixtures:  
Natural Uranium Nuclide Selector

Total activity:  
Bequerel 2.557e+004

Reference point:  
Measurement start

Measurement setup Calculation results Options

Gamma Spectrum Generator Settings:

- ☒ Display detector efficiency curves
- ☒ Consider decay transformations during cooling and counting time intervals
  - ☒ Include gamma-rays of daughter nuclides
  - 0.01 Decay Engine's accuracy factor
- ☒ Consider effects of backscatter radiation
  - 1.0 Backscatter peak normalisation factor

Done Local intranet 100%

Efficiency Graph  
can be activated  
in the Calculation  
Results output

The backscatter  
peak simulation  
can be switched  
on/off, and its  
contribution to  
the spectrum can  
be adjusted

Decay  
calculations can  
be enabled that  
will allow  
contributions  
from decay  
products, being  
accumulated  
during source  
cooling and  
spectrum  
measurement  
time intervals

## Features implemented: Calculation results

Statistical number of counts ▼

Count rate at start

Count rate at end

Theoretical number of counts

Statistical number of counts

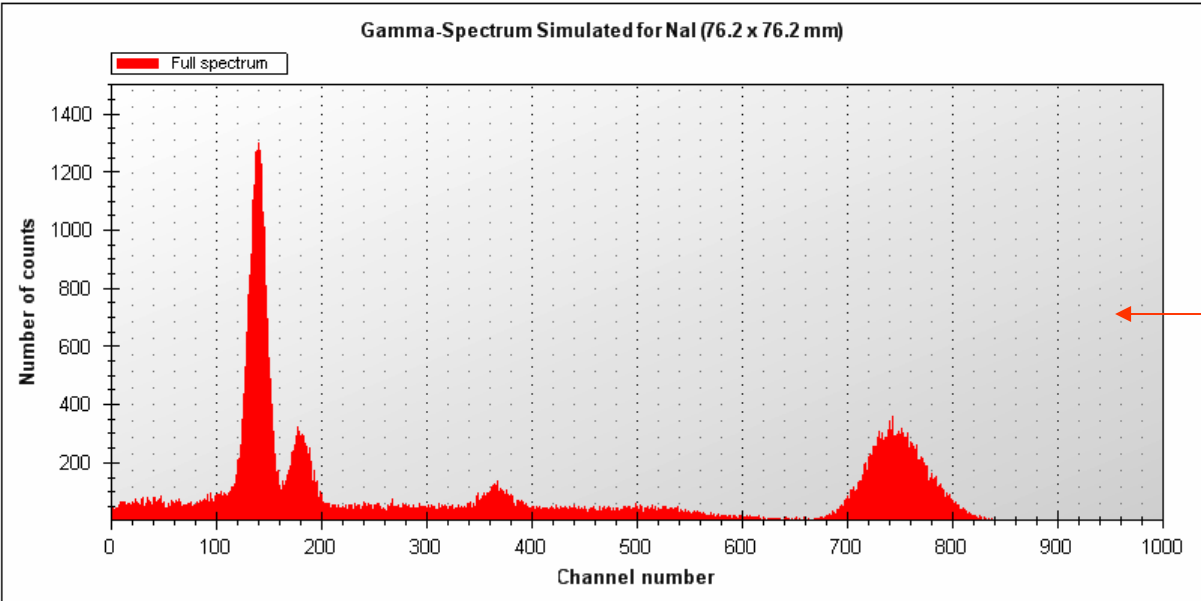
Measurement setup
Calculation results
Options

Data displayed:

Statistical number of counts ▼

View/Save results in Text or Excel format

**Gamma-Spectrum Simulated for NaI (76.2 x 76.2 mm)**



Update spectrum graph

Display: ☐ Energy scale
☐ Spectrum continuum
☐ Contribution of scattered photons
☐ More graph options

No.	Nuclide	Count rate at start, cps	Count rate at end, cps	Spectrum counts	Display
1	42 Mo 99	6.23E+01	6.22E+01	6.26E+04	<input type="checkbox"/>
2	43 Tc 99	6.70E-15	6.79E-15	0.00E+00	<input type="checkbox"/>
3	43 Tc 99m	2.69E+01	2.68E+01	2.70E+04	<input type="checkbox"/>
<b>Total</b>		<b>8.92E+01</b>	<b>8.90E+01</b>	<b>8.97E+04</b>	

Complete set of spectral information can be downloaded as a text or Excel spreadsheet file

Right click within the graph area enables a context menu, from which one can print or download the spectrum graph

Additional options allow to customize appearance of the graph to meet one's needs and requirements

Switch between channel number and energy scale; show peak, continuum and backscatter peak contributions to the full spectrum

Display nuclide specific contributions to the full spectrum



## Calculation results : Detailed Spectral Data in Excel Spreadsheet

**Calculation Parameters**

Nucleonica - GAMMA SPECTRUM GENERATOR Version 1.0.0.1			
File content: Calculation Results			
Created: 4/17/2008 3:21:29 PM (UTC)			
<b>SPECTROMETER:</b>			
Configuration name	Noname		
Crystal type	HPGe		
Crystal length	52.00	mm	
Crystal diameter	72.20	mm	
Contact length	36.00	mm	
Contact diameter	10.00	mm	
Inactive layer	0.90	mm	Germanium
Crystal packaging	5.00	mm	Vacuum
Detector input window	1.50	mm	Aluminum
Number of additional filters	0.00		
Filter No.1	0.00	mm	
Filter No.2	0.00	mm	
Filter No.3	0.00	mm	
Filter No.4	0.00	mm	
Filter No.5	0.00	mm	
Filter No.6	0.00	mm	
FWHM at 122 keV	0.00		
FWHM at 1332.5 keV	0.00		
Number of channels	8192		
Channel-to-Energy conversion	1.036E+01		
Source-to-Detector distance	65	cm	
Spectrum measurement time	67	min	
<b>SOURCE:</b>			
Nuclide	56 Ba 137m		
Quantity	570		
Reference point of time	N		
Source cooling interval	30	min	
<b>CALCULATION:</b>			
Consider decay transformations	Yes		
Include gammas of daughter nuclides	Yes		
Decay engine's accuracy factor	0.01		
Consider backscatter radiation	Yes		
Backscatter peak normalization factor	2		

**Nuclide Specific Data**

Nuclide	Ancestor	Activity, Bq		Number of decays	Count rate, cps		Number of counts	
		at start	at end		at start	at end	theor.	statist.
55 Cs 137	55 Cs 137	1.000E+00	1.000E+00	1.000E+00	5.652E-08	5.652E-08	5.652E-08	0.000E+00
56 Ba 137m	55 Cs 137	9.437E-01	9.395E-01	9.416E-01	7.177E-03	7.144E-03	7.160E-03	0.000E+00
<b>TOTAL:</b>		<b>0.000E+00</b>	<b>0.000E+00</b>	<b>0.000E+00</b>	<b>7.177E-03</b>	<b>7.144E-03</b>	<b>7.160E-03</b>	<b>0.000E+00</b>

**Gamma and X-ray Data**

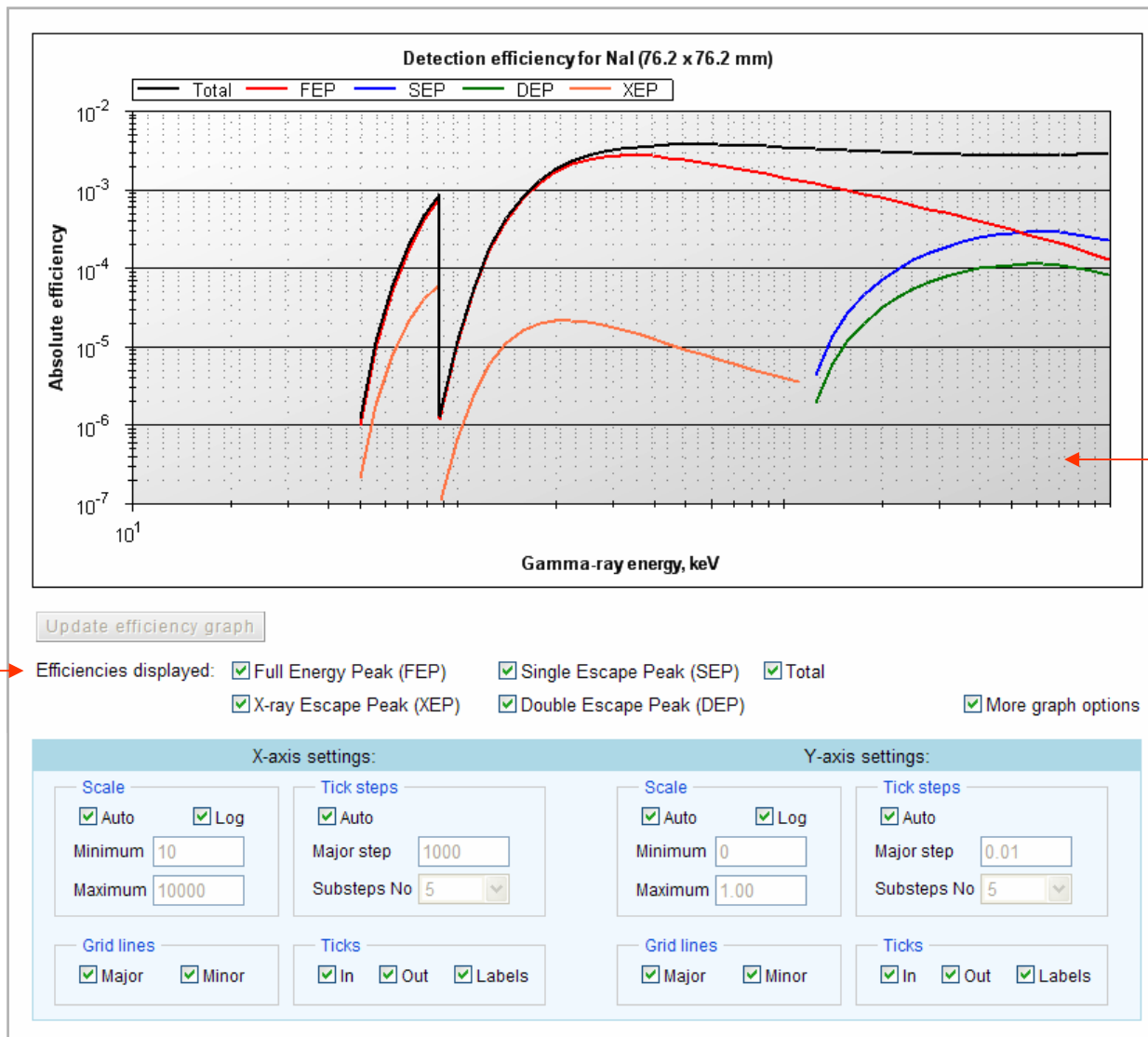
Energy, keV	X/G ray	Emission rate, 1/s at start	Emission rate, 1/s at end	Photons emitted	Peak region counts peak area	Peak region counts peak bkg	Detection efficiency total	FEP	Ancestor's MDA(0), Bq
350	G	5.800E-06	5.800E-06	5.800E-06	2.715E-08	4.094E-05	7.530E-03	4.681E-03	1.441E+08
47	X	9.837E-03	9.793E-03	9.815E-03	0.000E+00	2.757E-05	0.000E+00	0.000E+00	NAN
82	X	1.951E-02	1.943E-02	1.947E-02	5.198E-07	3.363E-05	2.775E-05	2.676E-05	9.635E+08
19	X	3.600E-02	3.584E-02	3.592E-02	1.137E-06	3.301E-05	3.285E-05	3.171E-05	1.997E+08
40	X	1.310E-02	1.304E-02	1.307E-02	2.193E-06	3.211E-05	1.727E-04	1.681E-04	5.304E+07
66	G	8.500E-01	8.462E-01	8.481E-01	1.960E-03	2.144E-06	6.715E-03	2.311E-03	1.964E+03

**Gamma Spectrum**

Energy, keV	Count rate at start, cps			Count rate at end, cps			Theoretical number of counts		
	Continuum	Scattered	Total	Continuum	Scattered	Total	Continuum	Scattered	Total
0.20	2.637E-06	8.042E-07	2.650E-06	2.625E-06	8.006E-07	2.638E-06	2.631E-06	8.024E-07	2.644E-06
0.60	3.185E-06	9.725E-07	3.218E-06	3.171E-06	9.681E-07	3.204E-06	3.178E-06	9.703E-07	3.211E-06
1.00	3.335E-06	1.019E-06	3.376E-06	3.320E-06	1.015E-06	3.360E-06	3.327E-06	1.017E-06	3.368E-06
1.40	3.381E-06	1.035E-06	3.394E-06	3.366E-06	1.030E-06	3.379E-06	3.373E-06	1.032E-06	3.387E-06
1.80	3.400E-06	1.042E-06	3.401E-06	3.385E-06	1.037E-06	3.385E-06	3.392E-06	1.039E-06	3.393E-06
2.20	3.411E-06	1.046E-06	3.411E-06	3.396E-06	1.042E-06	3.396E-06	3.404E-06	1.044E-06	3.404E-06
2.60	3.421E-06	1.050E-06	3.421E-06	3.405E-06	1.046E-06	3.405E-06	3.413E-06	1.048E-06	3.413E-06



## Calculation results : Detection Efficiency



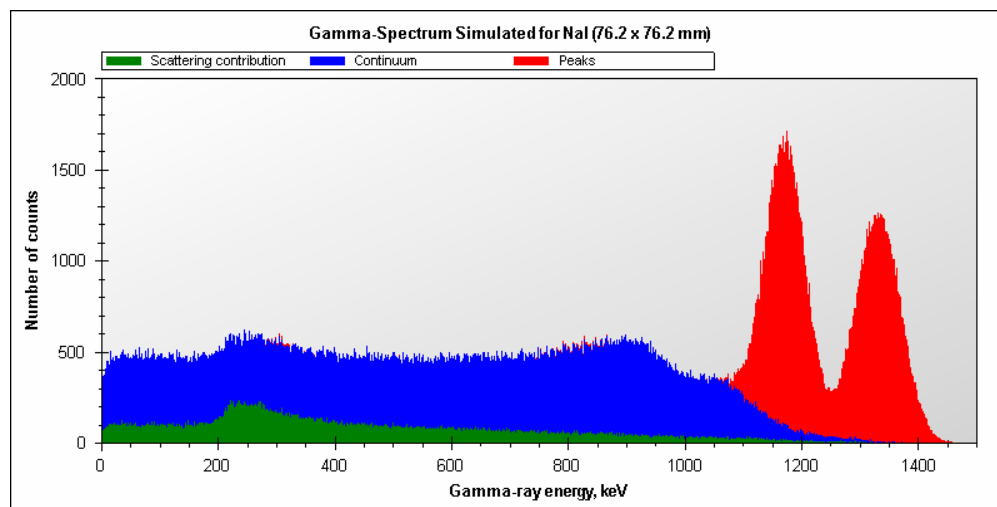
Select efficiency data to be displayed on the graph

Right click within the graph area enables a context menu, from which one can print or download the efficiency graph

Additional options allow to tailor the efficiency graph to one's needs and requirements

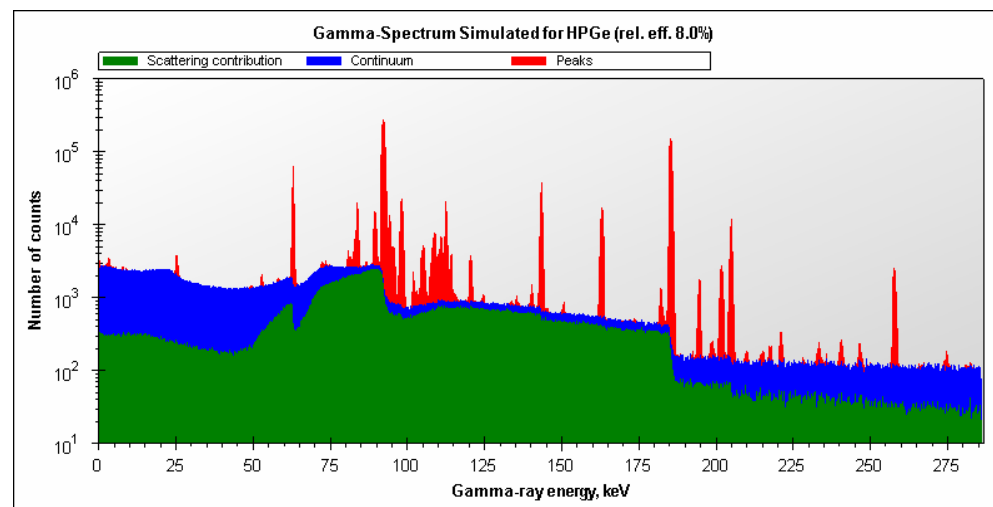
## Examples:

### 100 kBq $^{60}\text{Co}$



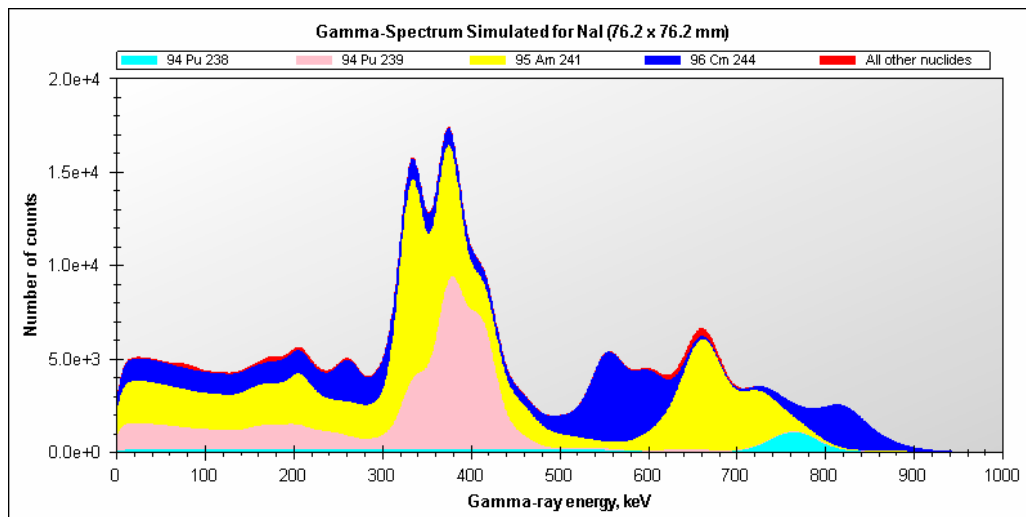
Detector - NaI (Ø3"×3")  
Source-to-detector distance - 25 cm  
Measurement time - 1000 s

### 1 g Nat U (2 years after separation)

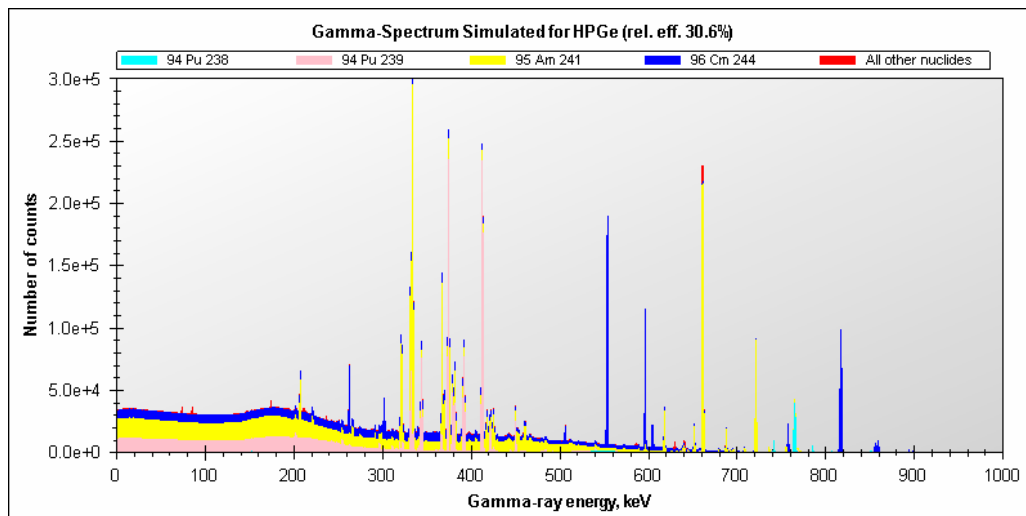


Detector – LEGe (20 mm × 2800 mm<sup>2</sup>)  
Source-to-detector distance – 25 mm  
Filter – 0.5 mm Sn  
Measurement time - 10<sup>5</sup> s

## Examples:



Detector – NaI (Ø3"×3")  
Source-to-detector distance – 25 cm  
Filter – 5 mm Pb  
Measurement time - 1000 s



**Actinides extracted from 1 kg 6-year-aged PWR spent fuel. Activity - 5.25 TBq**

Detector – BEGe (30% rel. eff.)  
Source-to-detector distance – 25 cm  
Filter – 5 mm Pb  
Measurement time - 1000 s

## Experimental validation with 60% HPGe coaxial detector (INR, Kiev)

**Detector:** coaxial HPGe (Canberra)

- Relative efficiency: 61.8%
- Crystal dimensions:  $\varnothing 74 \text{ mm} \times 53 \text{ mm}$
- Rear contact:  $\varnothing 10 \text{ mm} \times 36 \text{ mm}$
- Inactive Ge: 0.7 mm
- Crystal end cap: 1.5 mm Al
- End cap to crystal gap: 5 mm
- FWHM: 1.75 keV at 1.33 MeV

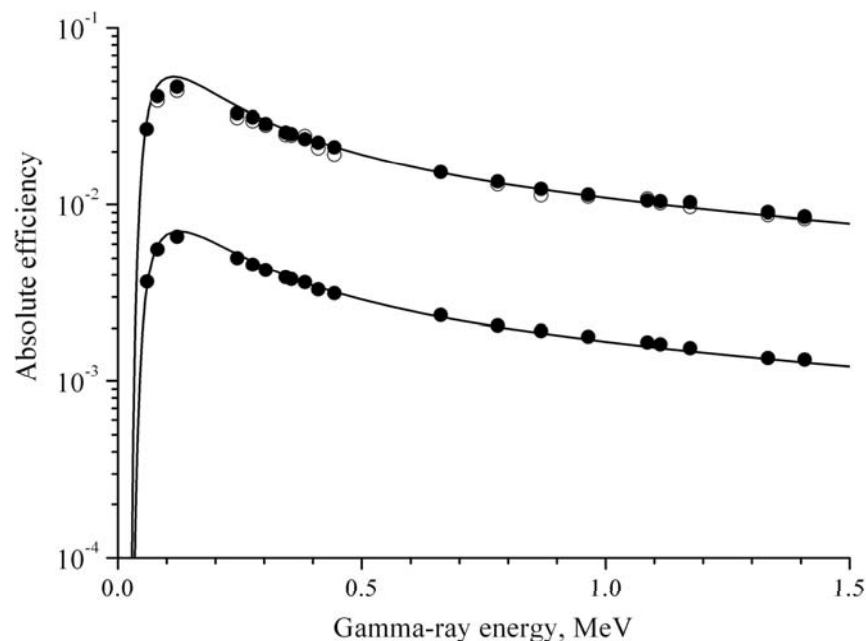
**Sources:** Thin Spectroscopic Reference Gamma-Sources (SOSGI)

- $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ ,  $^{152}\text{Eu}$

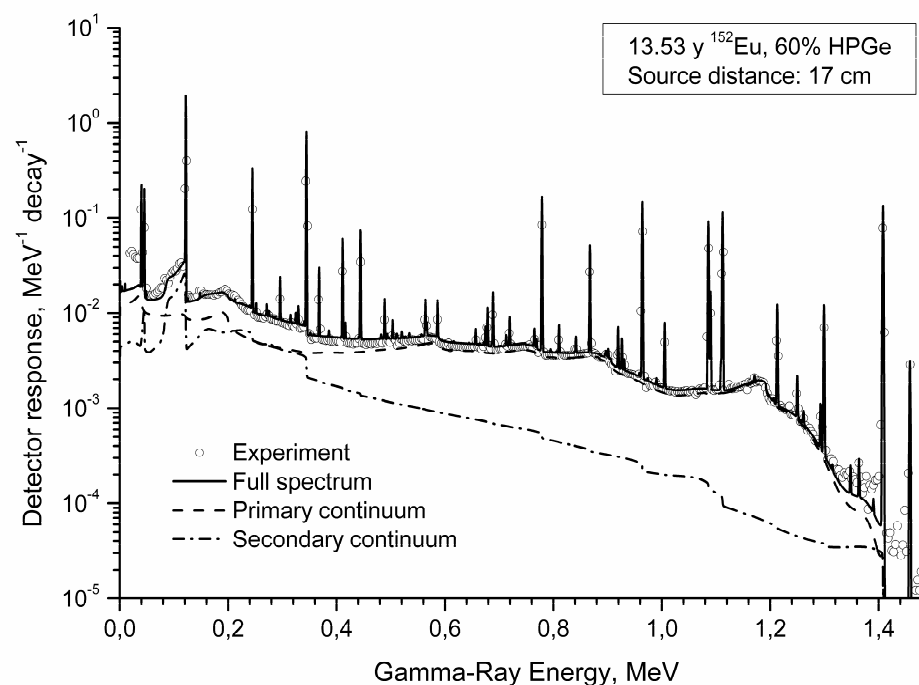
**Measurement conditions:** Center of experimental room



## Results of the experimental validation with 60% HPGe coaxial detector



Full Energy Peak efficiency as a function of the photon energy: circles – experimental values, curve – calculated. Two sets of data refer to the source location at 5 cm and 17 cm distances from the detector end cap.



Calculated (curve) and experimental (circles) detector responses for  $^{152}\text{Eu}$  source at 17 cm distance from the detector end cap.



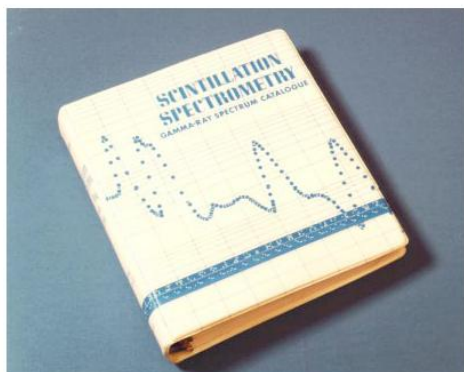
REVISED EDITION OF REPORT IDO - 16880 - 1  
ORIGINAL ISSUED: AUGUST 1964  
REV. ELECTRONIC UPDATE: FEBRUARY 1997

## SCINTILLATION SPECTROMETRY GAMMA-RAY SPECTRUM CATALOGUE

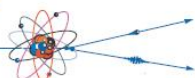
NEW VERSION OF 2ND EDITION  
COMPILATION OF GAMMA-RAY SPECTRA  
AND RELATED NUCLEAR DECAY DATA  
VOLUME 1 OF 2

BY

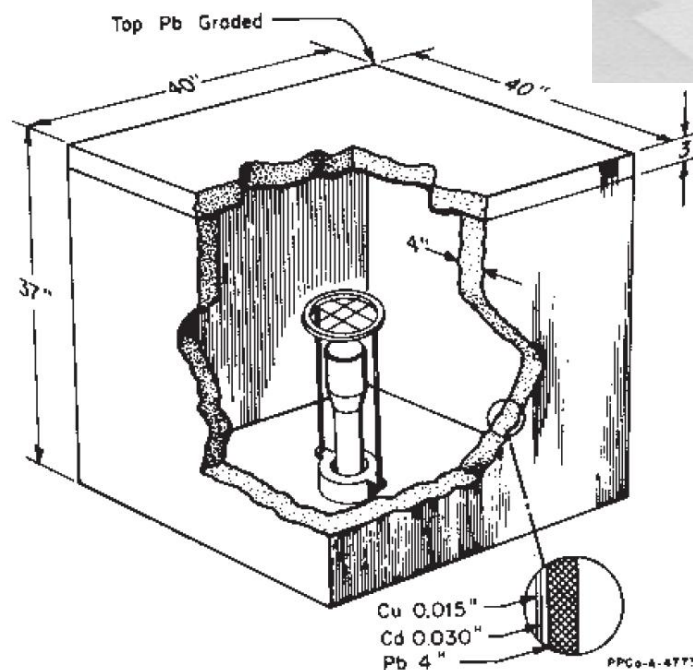
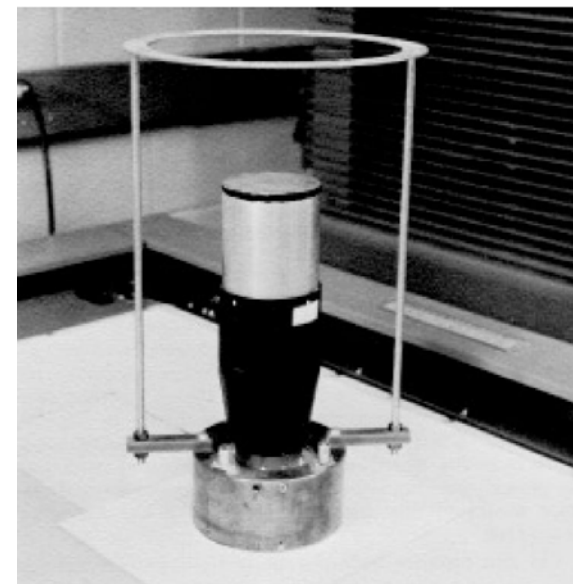
**R. L. HEATH**



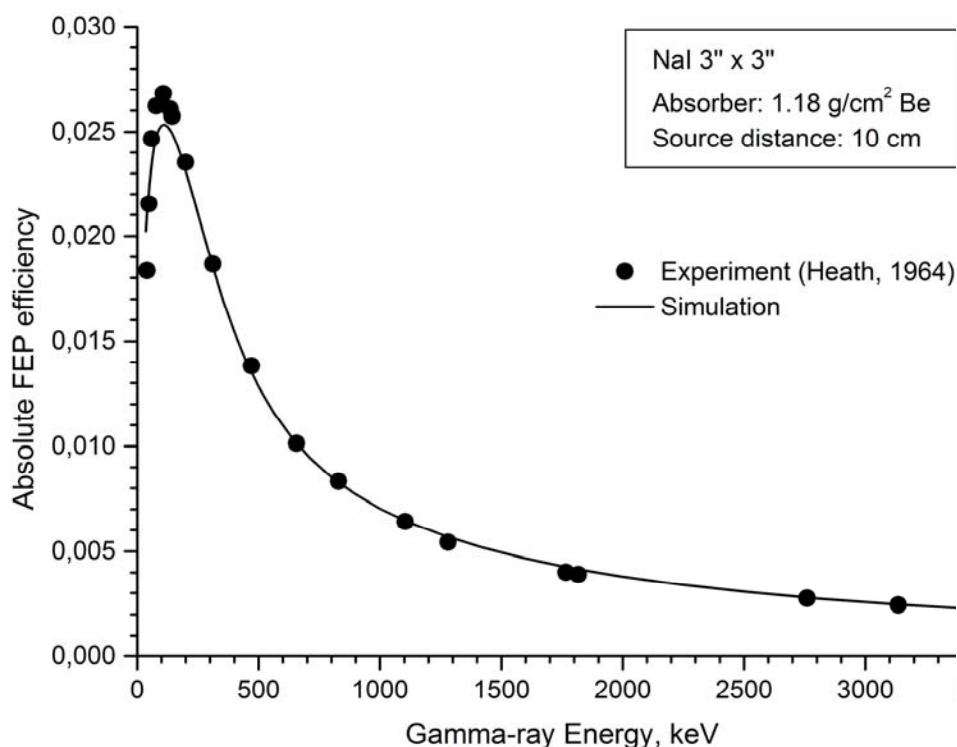
**-RAY SPECTROMETRY CENTER**  
Idaho National Engineering & Environmental Laboratory



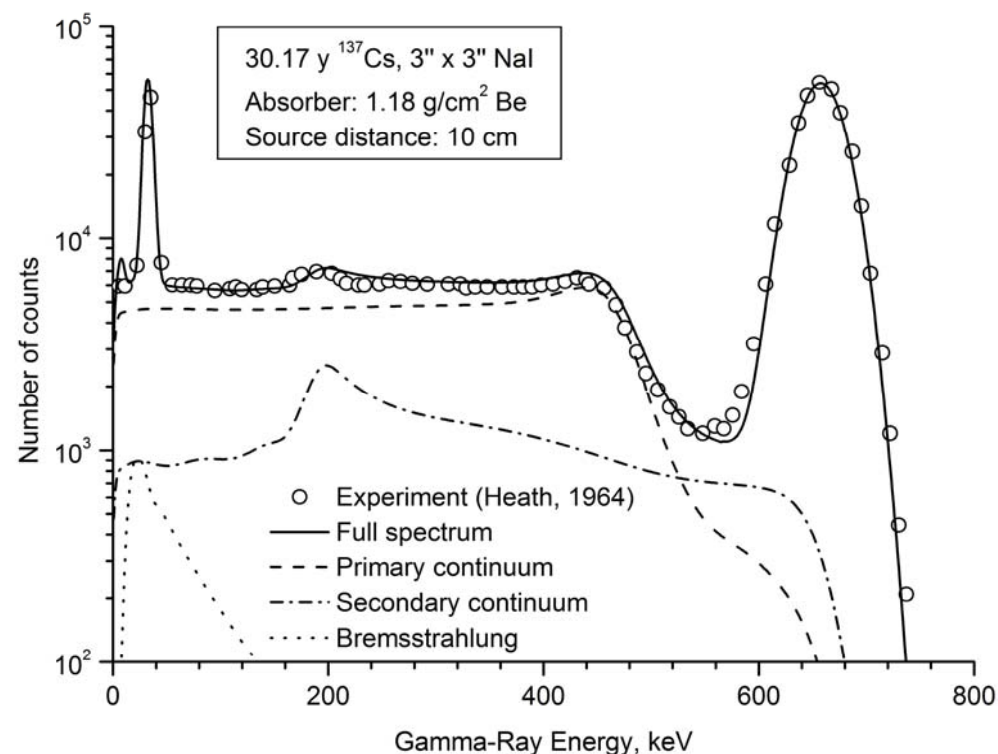
**Detector:**  
3" × 3" NaI scintillation  
detector



## Results of the experimental validation with 3" × 3" NaI scintillation detector

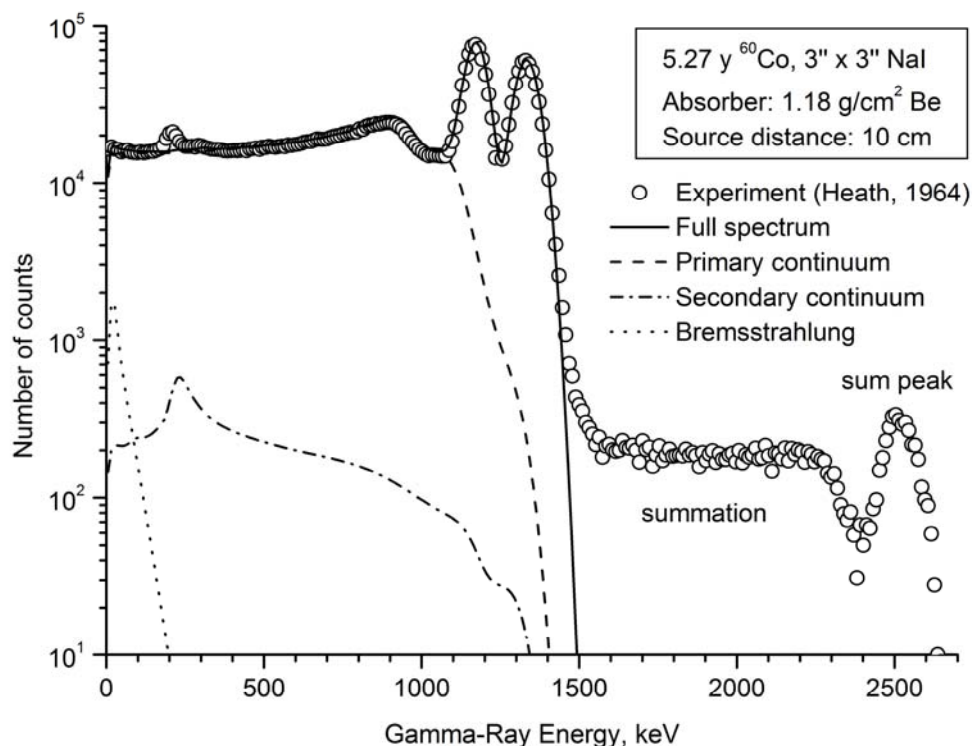


The simulated vs. experimental *FEP* efficiencies for a NaI 3" × 3" detector.

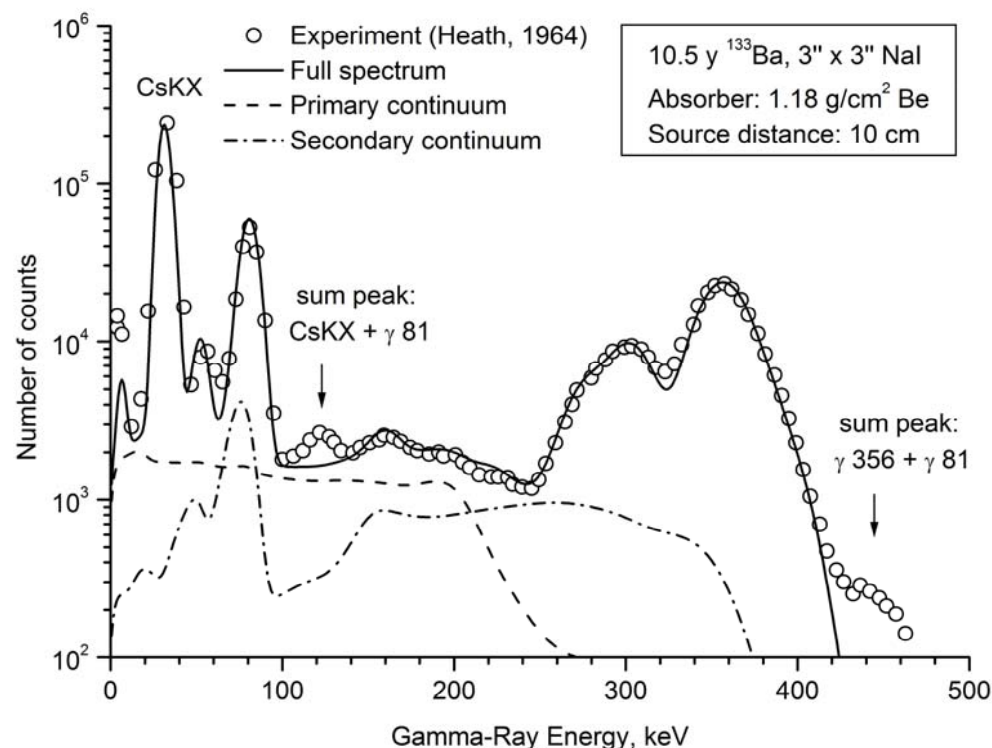


The experimental and simulated spectra for <sup>137</sup>Cs and a NaI 3" × 3" detector .

## Results of the experimental validation with 3" × 3" NaI scintillation detector

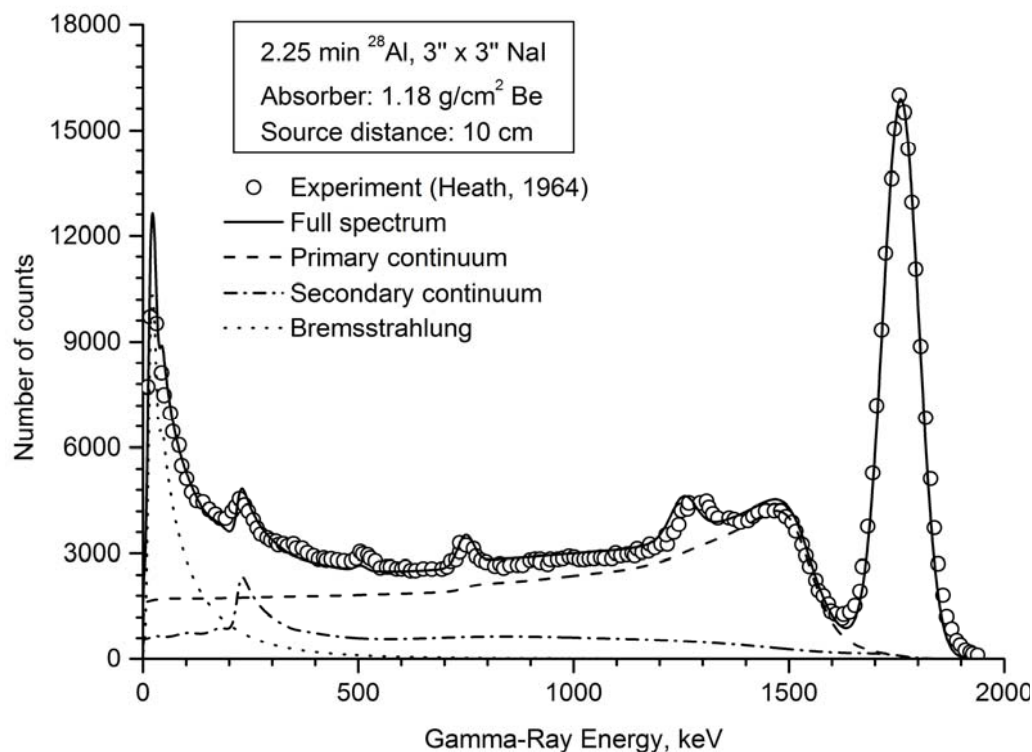


The experimental and simulated spectra for  $^{60}\text{Co}$  and a NaI 3" × 3" detector.

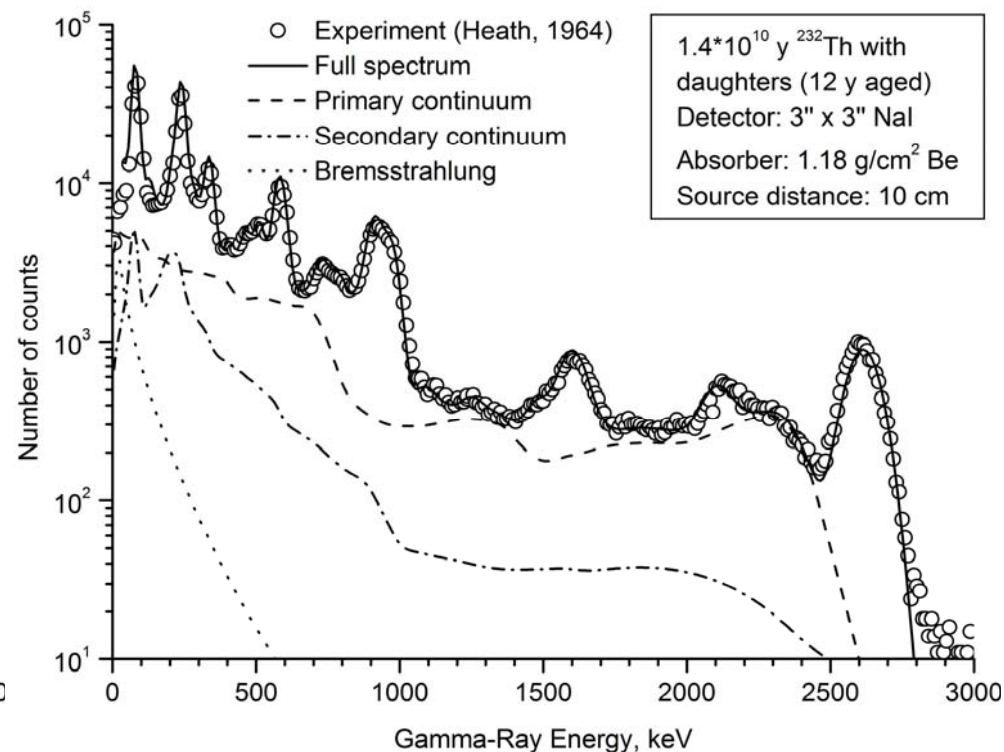


The experimental and simulated spectra for  $^{133}\text{Ba}$  and a NaI 3" × 3" detector.

## Results of the experimental validation with 3" × 3" NaI scintillation detector



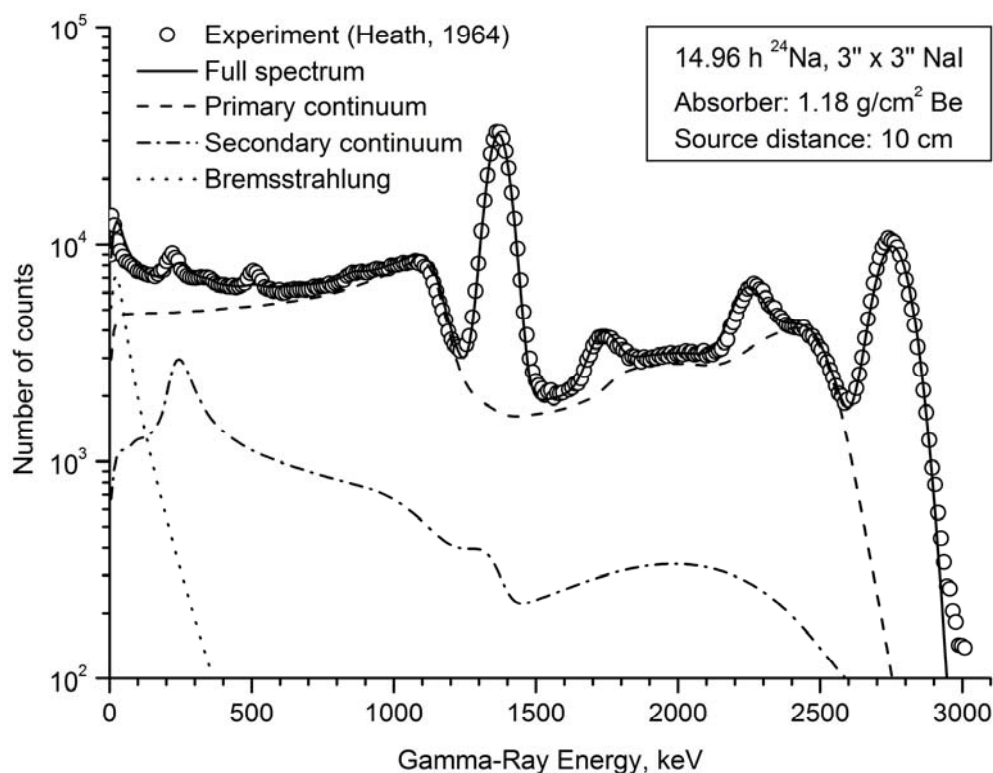
The experimental and simulated spectra for  $^{28}\text{Al}$  and a NaI 3" × 3" detector .



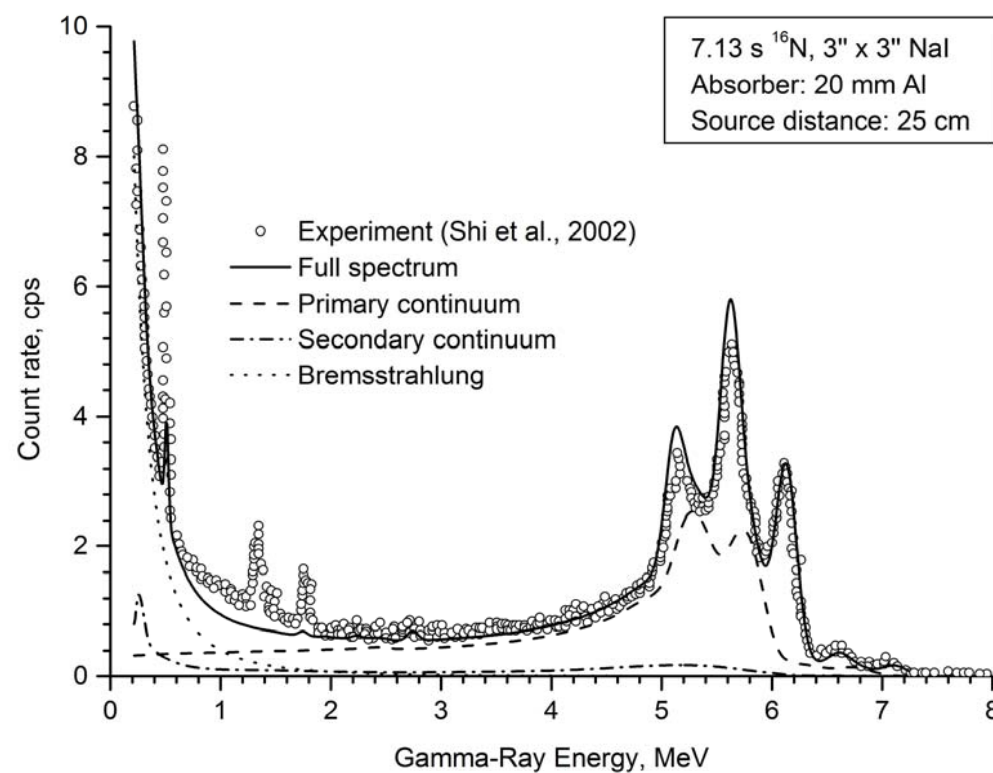
The experimental and simulated spectra for a 12 year old  $^{232}\text{Th}$  source and a NaI 3" × 3" detector.



## Results of the experimental validation with 3" × 3" NaI scintillation detector



The experimental and simulated spectra for  $^{24}\text{Na}$  and a NaI 3" × 3" detector.



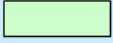



The experimental and simulated spectra for  $^{16}\text{N}$  and a NaI 3" × 3" detector.



## New feature #1: Modeling background gamma spectrum from naturally occurring radionuclides, which makes the spectrum shape and MDA evaluations to be more realistic

Additional measurement setup properties:

	Absorbing filter layers:	Aluminum	1.0	Add	Del	No.	Layer material	Thickness
	Input window:	Aluminum	0.5					
	Crystal packaging:	Foam Plastic	0.0					
	Inactive layer / Reflector:	Aluminium oxide	0.5					

ADC and energy resolution parameters:

2048	Number of spectrum channels	18.0	Energy resolution (FWHM) at 122 keV, keV
1.0	Channel-to-energy conversion factor, keV/channel	90.0	Energy resolution (FWHM) at 1332 keV, keV

Background gamma-ray peak and continuum intensities, cps:

0.013	Count rate in 185.7 keV peak of U-235	0.0003	Count rate in 661.6 keV peak of Cs-137
0.012	Count rate in 238.6 keV peak of Pb-212 (Th-232)	0.00015	Count rate in 1332.5 keV peak of Co-60
0.035	Count rate in annihilation 511.0 keV peak	0.02	Count rate in 1460.8 keV peak of K-40
0.008	Count rate in 609.3 keV peak of Bi-214 (U-238)	3	Continuum count rate (0 - 3 MeV)

Measurement setup   Calculation results   Options

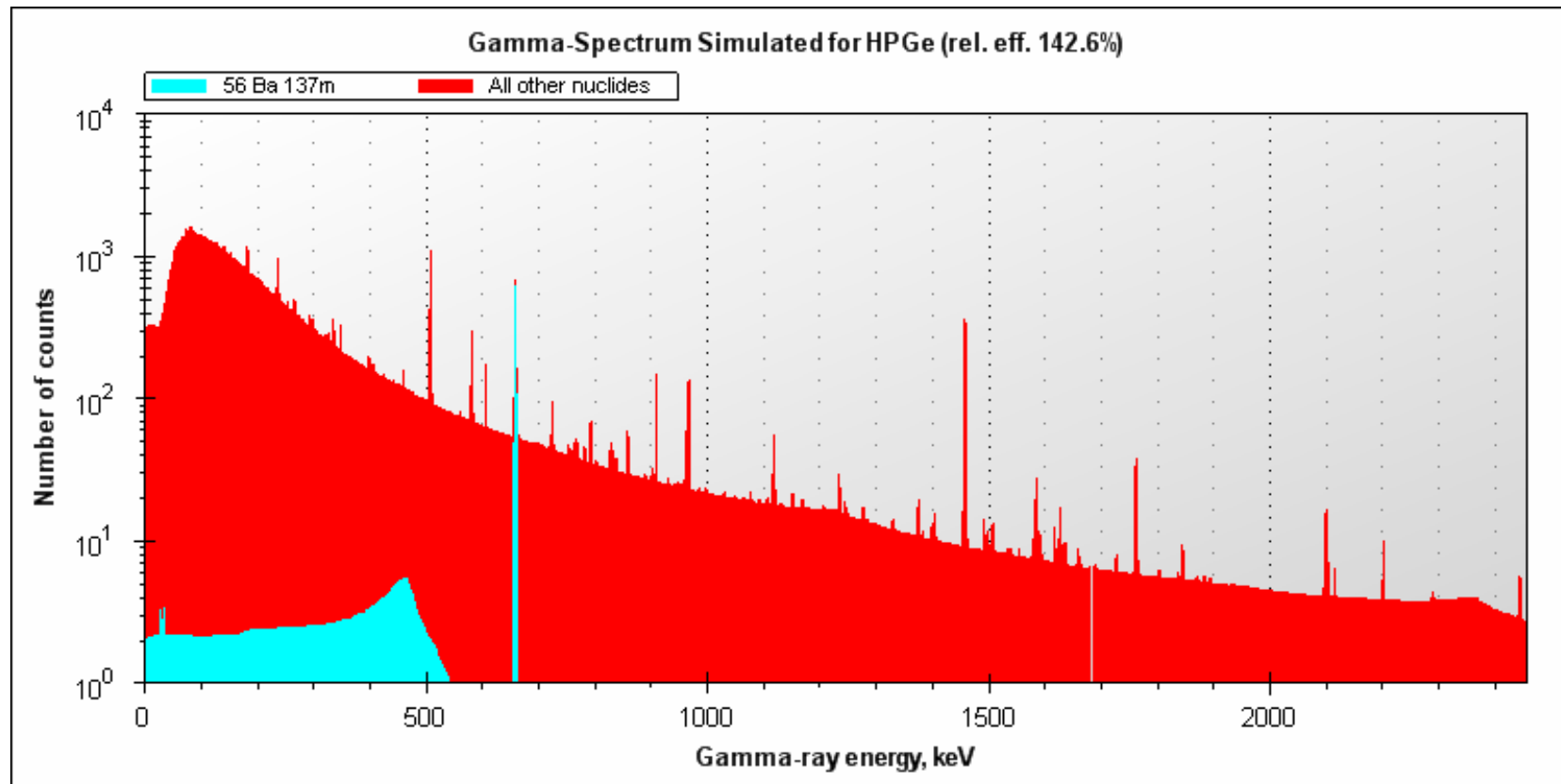
Gamma Spectrum Generator Settings:

- ☐ Display detector efficiency curves
- ☐ Consider decay transformations during cooling and counting time intervals
- ☐ Consider effects of backscatter radiation
- ☐ Consider bremsstrahlung photon creation
- ☒ Simulate natural gamma-ray background

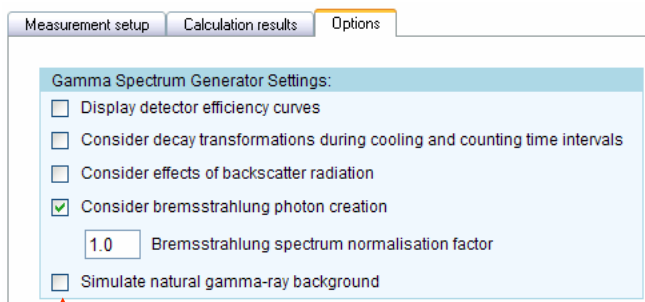
A respective option has to be selected on „Options“ tab to enable the background simulation

### Example: Natural background simulation

- a 10 Bq  $^{137}\text{Cs}$  source at 10 mm distance from 150% HPGe with natural background photons included

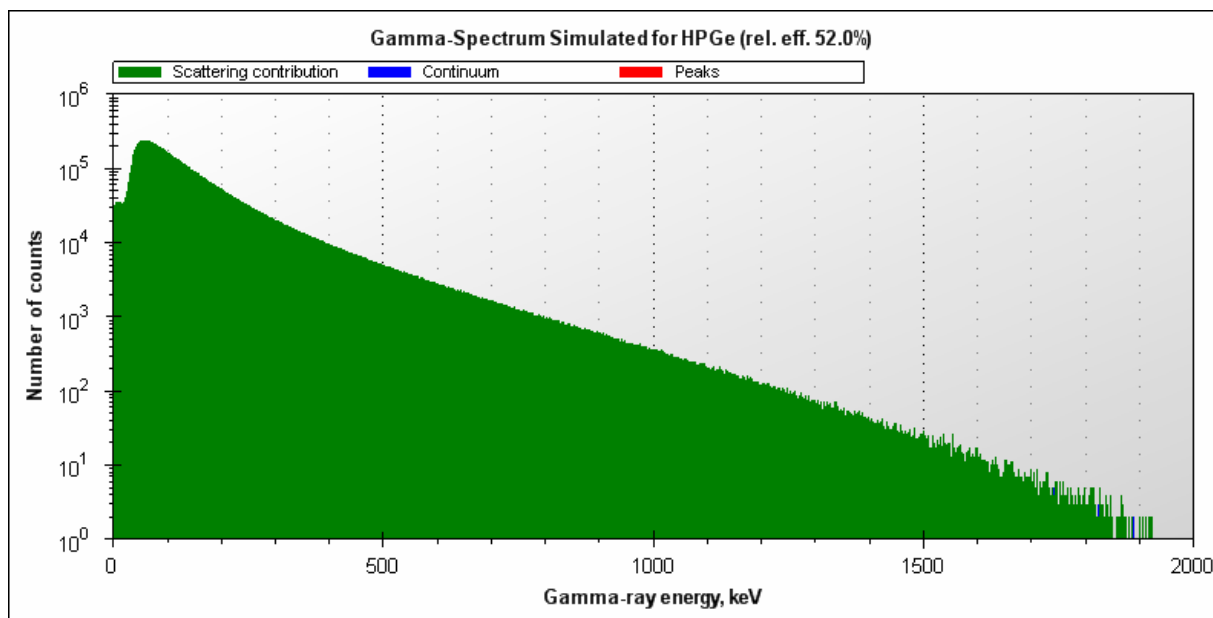


## New feature #2: Bremsstrahlung simulation

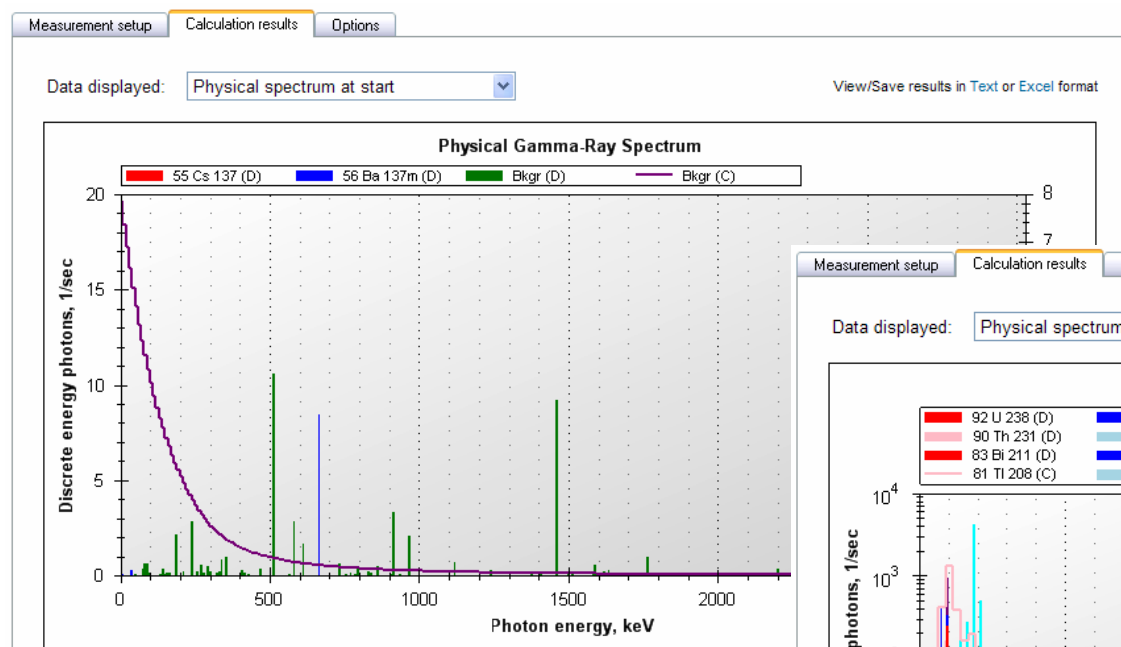


A respective option can be selected on „Options“ tab to enable the bremsstrahlung simulation.

A gamma-spectrum simulated for the 10 MBq  $^{90}\text{Sr}$ - $^{90}\text{Y}$  source and 50% HPGe

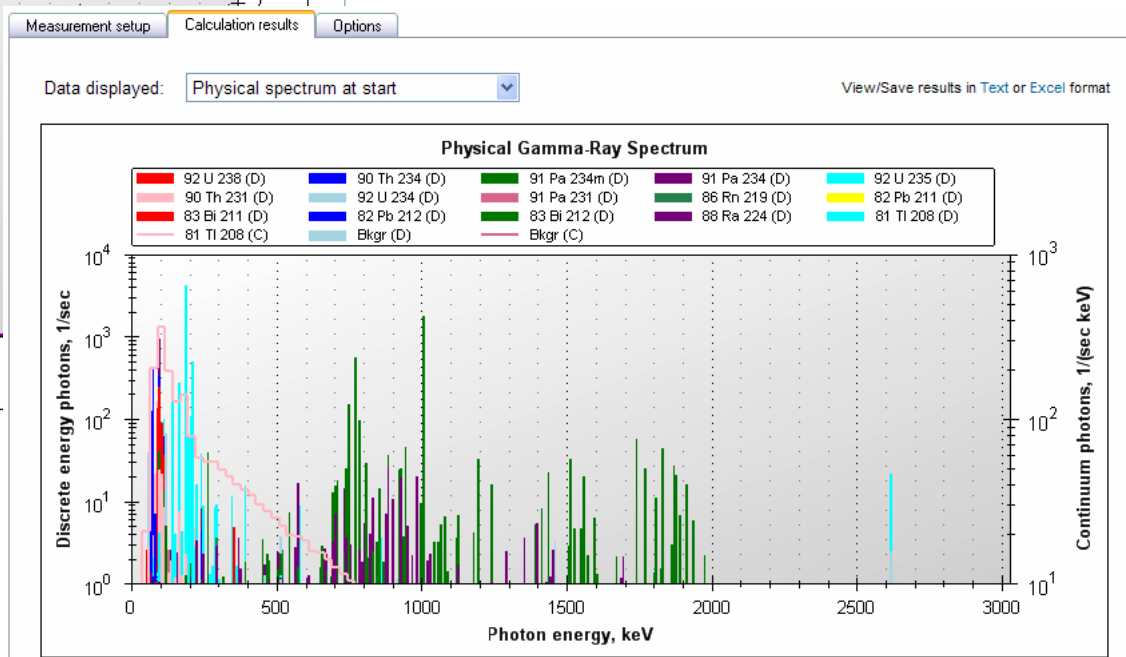


## New feature #3: Physical photon spectrum visualization

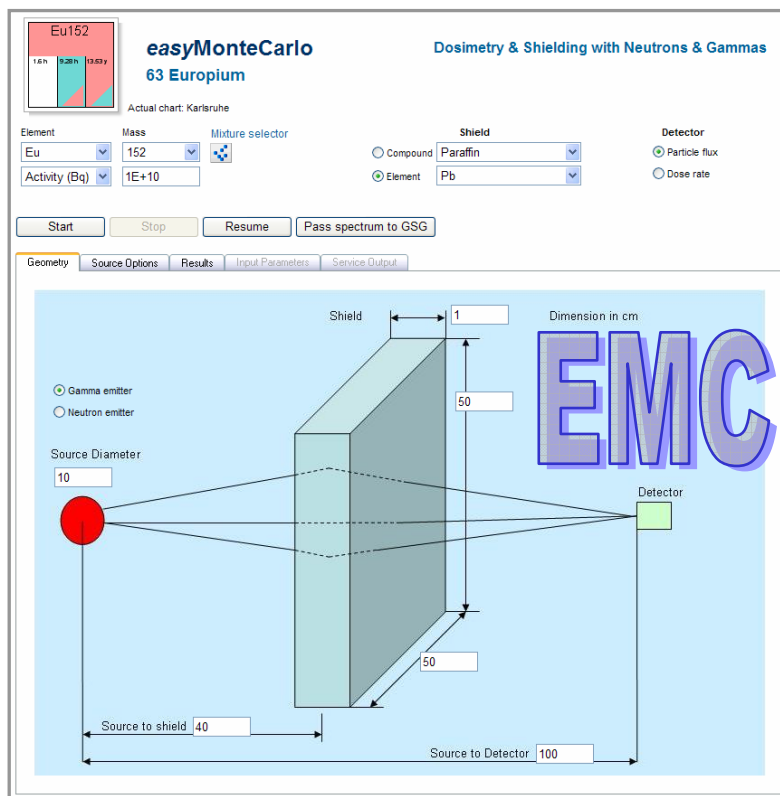


**<sup>137</sup>Cs source and natural background photons**

**4.46% Uranium source and natural background photons**

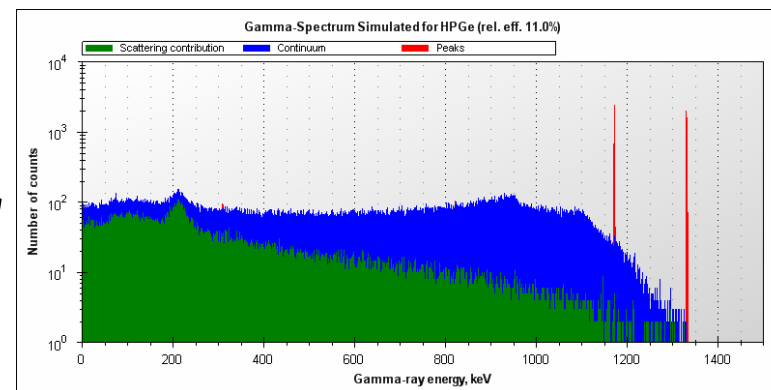


## New feature #4: Including self-attenuation and scattering effects, which would allow more realistic simulation of gamma-spectra from voluminous and shielded sources

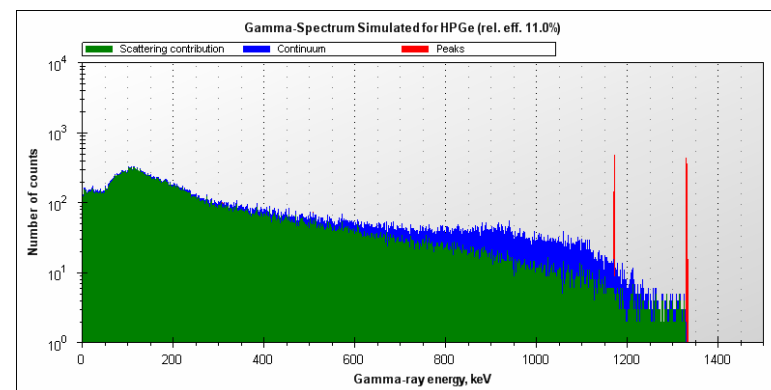


**GSG**

Unshielded <sup>60</sup>Co:

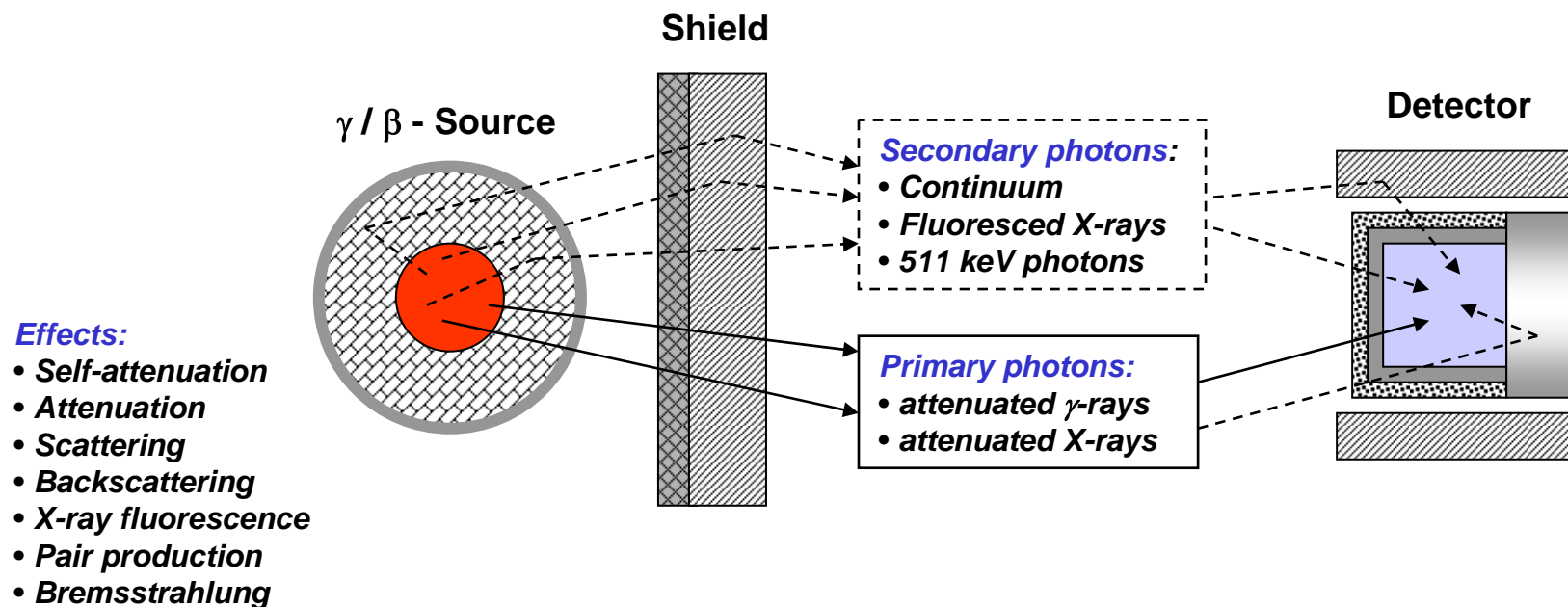


<sup>60</sup>Co behind 12 cm Al shield:





## Modelling $\gamma$ -spectra from volume / shielded sources:

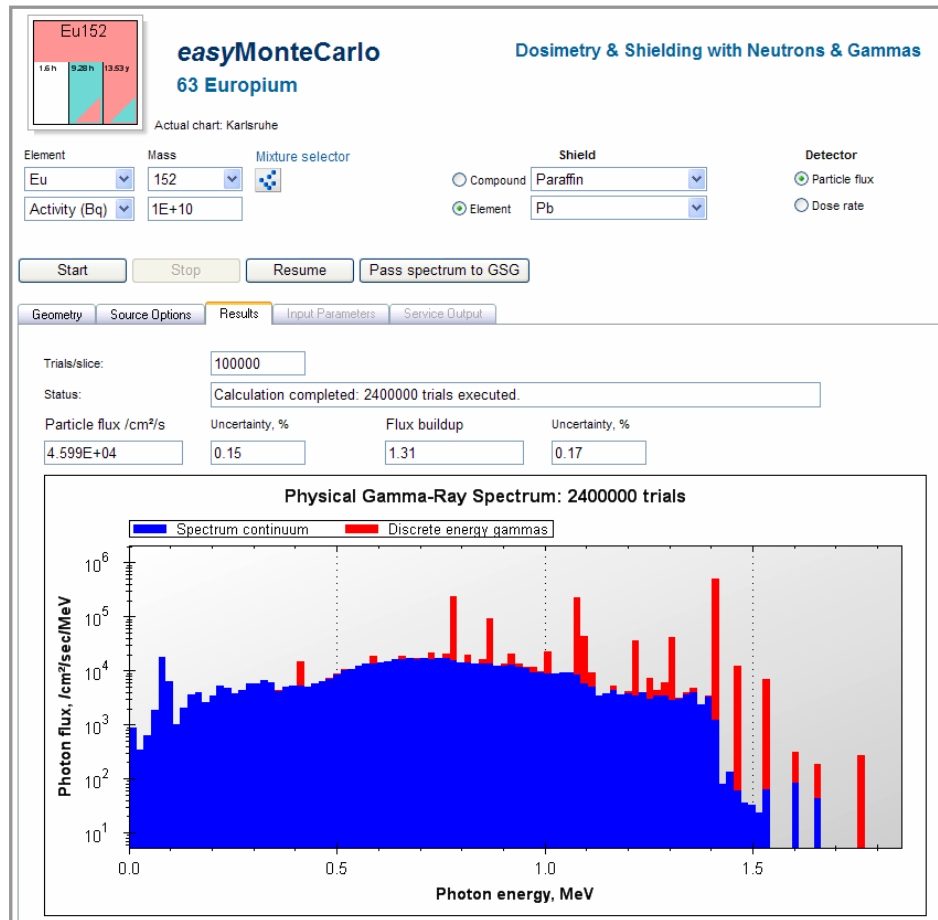


### Challenges:

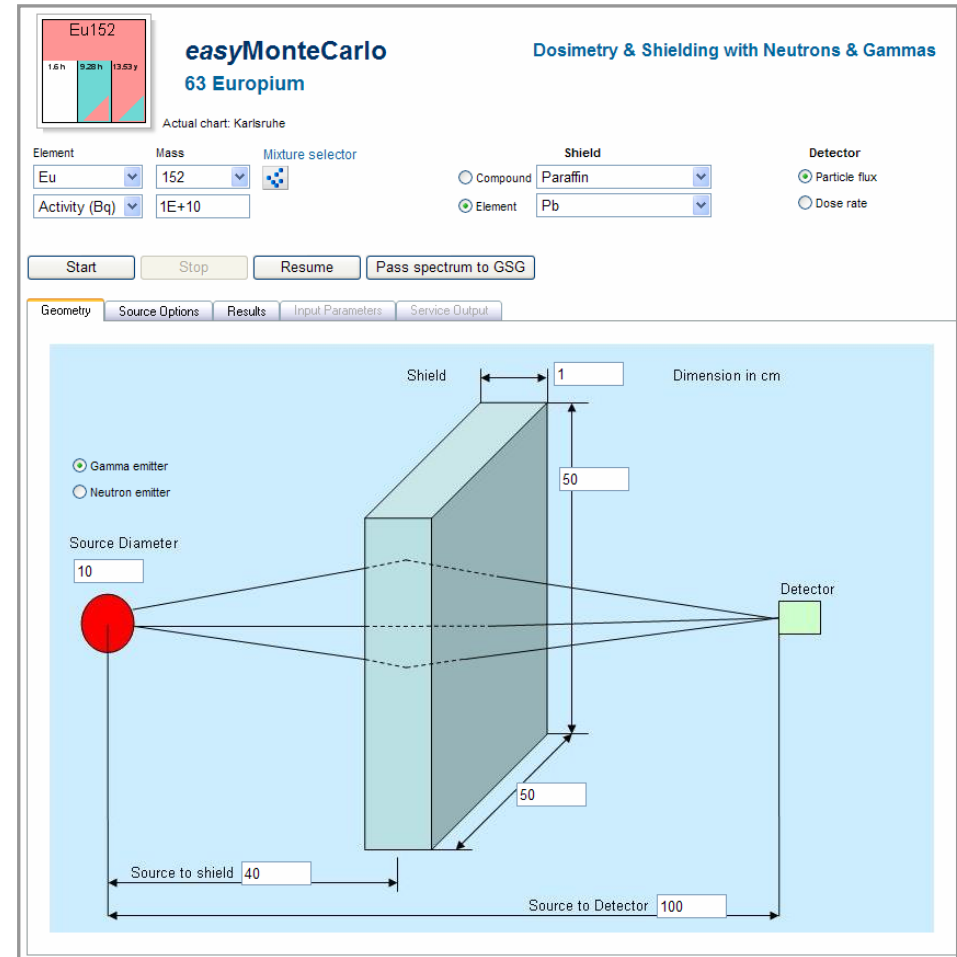
- an accurate reproduction of the incident photon flux properties is important;
- an accurate knowledge of the detector response in a broad energy range is required;
- a huge computational effort is normally needed.

## What is the EasyMonteCarlo?

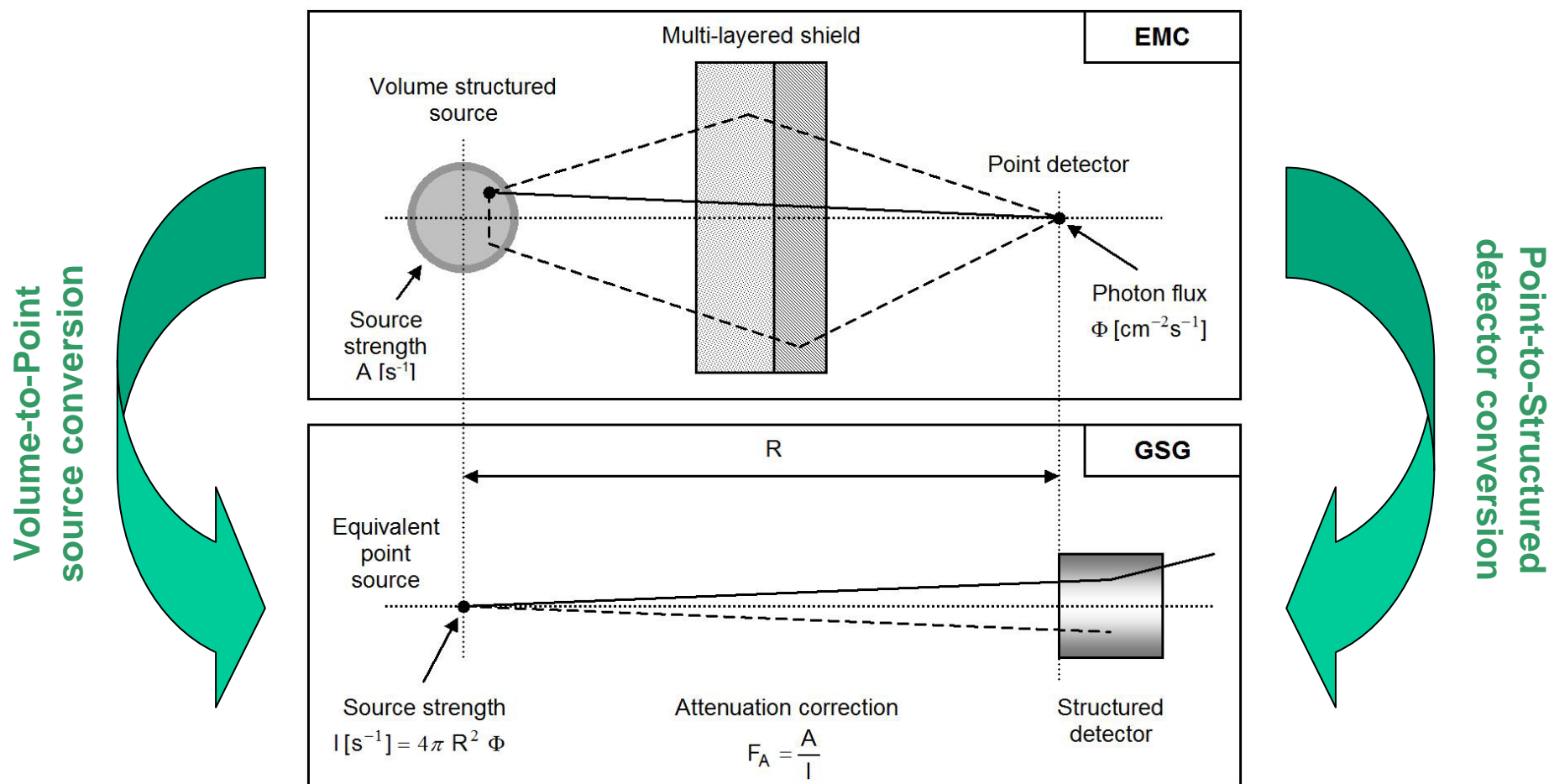
- A dedicated Monte Carlo **web-service**, i.e. a computational engine reachable to other programs via the Internet



## EMC Front End:



## Coupled EMC / GSG calculations for voluminous & shielded sources:



JRC Technical Notes

**RESTREINT UE**

## A Collection of Reference HPGe Gamma-Spectra for Shielded / Unshielded Radionuclide Sources and Special Nuclear Materials

Andrey Berlizov, Jurgita Jarmalaviciute, Klaus Mayer



JRC-ITU-TN-2009/25

**RESTREINT UE**

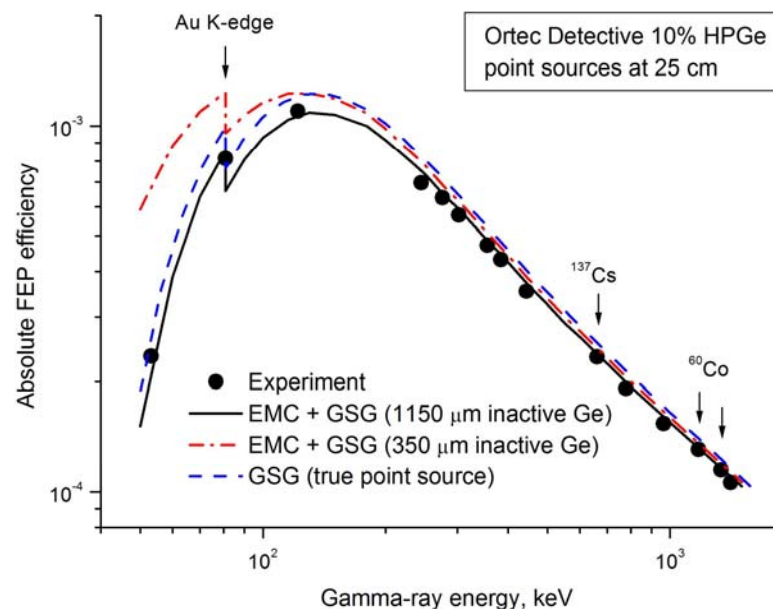
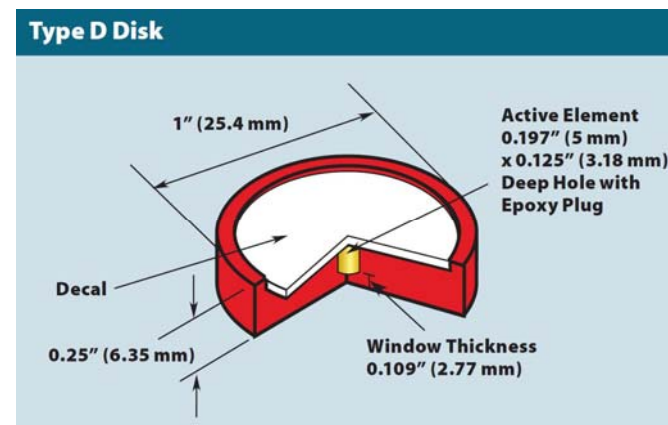
## Technical Report: JRC-ITU-TN-2009/25



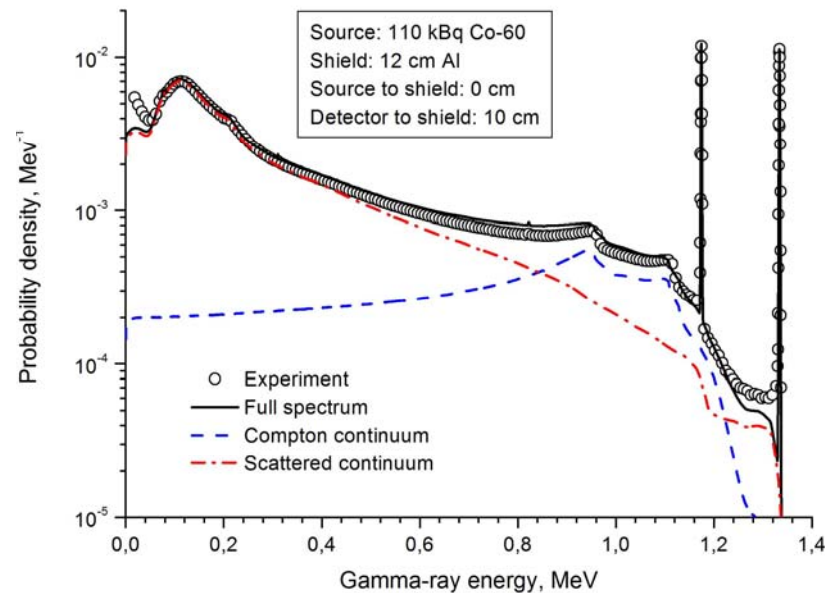
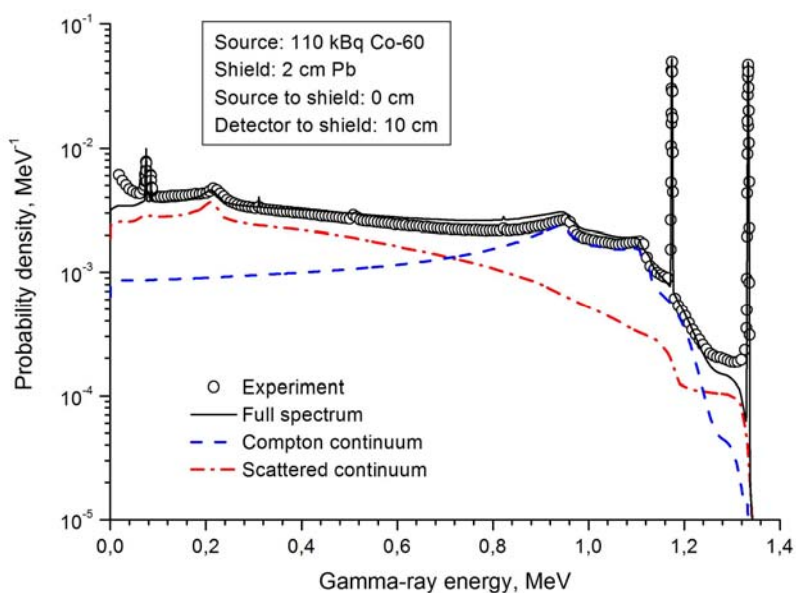
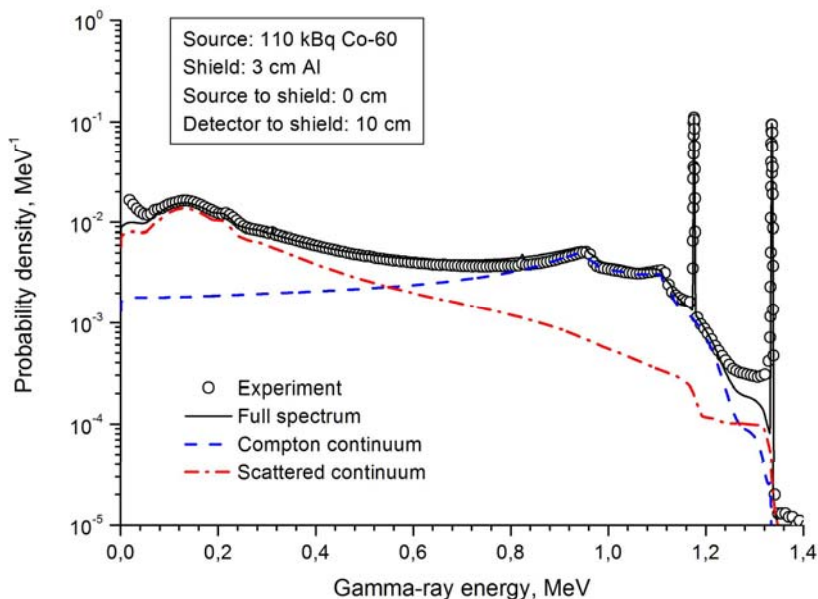
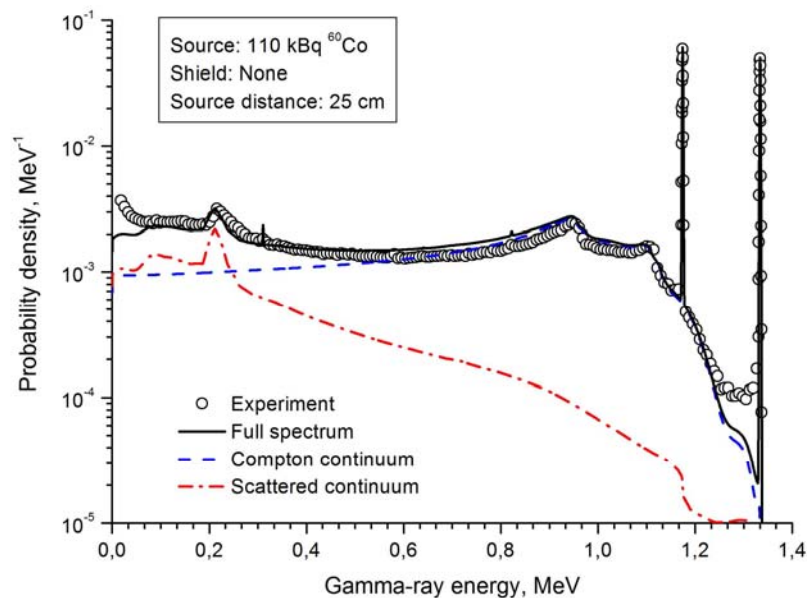


**Experimental room:**  $L \times W \times H = 3.3 \times 3.8 \times 3.5 \text{ m}^3$ .  
**Shields** ( $20 \times 20 \text{ cm}^2$ ): Pb (2 cm) and Al (3 cm, 12 cm).  
**Detector:** 10% Ortec Detective, HPGe  $\varnothing 50 \times 30 \text{ mm}$ .  
**Shield to detector:** 10 cm.  
**Source to shield:** 0 cm.  
**Unshielded sources:** at 25 cm distance.

**Type D Disk source:** Eckert & Ziegler Isotope Products, Reference & Calibration Sources, Product Information







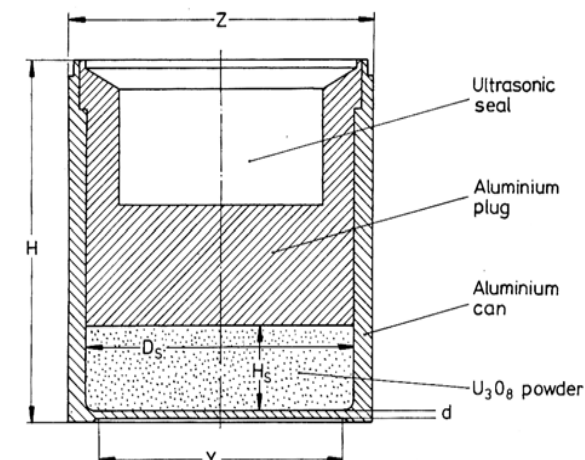


**Experimental room:**  $L \times W \times H = 3.3 \times 3.8 \times 3.5 \text{ m}^3$ .  
**Shields** ( $20 \times 20 \text{ cm}^2$ ): Pb (2 cm) and Al (3 cm, 12 cm).  
**Detector:** 10% Ortec Detective, HPGe  $\varnothing 50 \times 30 \text{ mm}$ .  
**Shield to detector:** 10 cm.  
**Source to shield:** 0 cm.  
**Unshielded source:** at 10 cm distance.

## CBNM-446 Uranium:

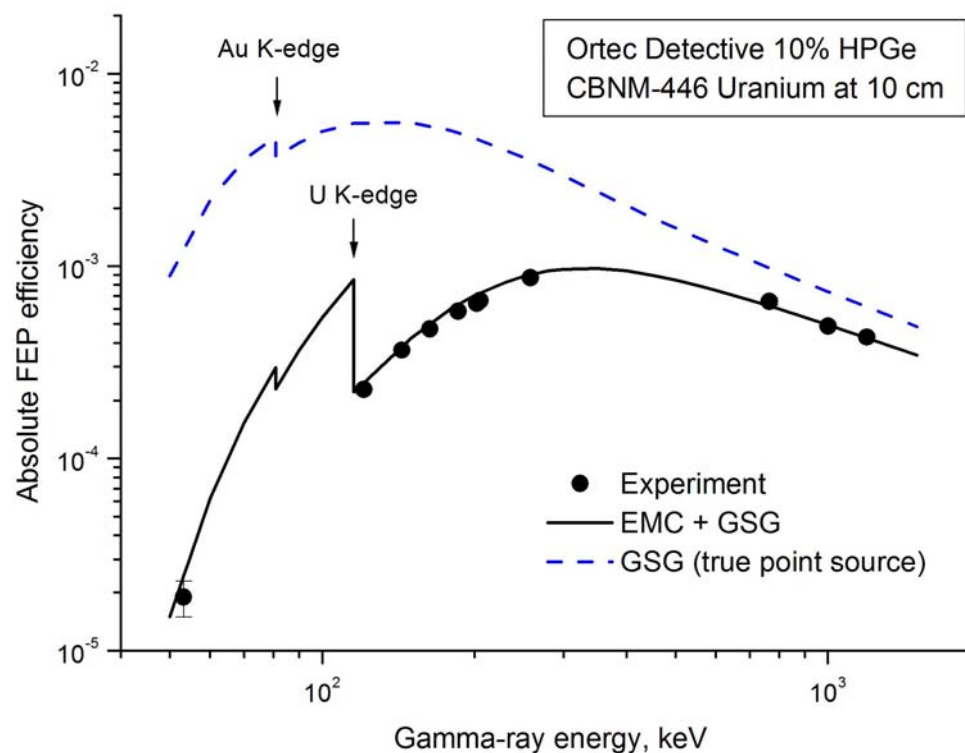
Separation date: 1979  
 $\text{U}_3\text{O}_8$ , 200 g,  $3.3 \text{ g/cm}^3$   
 Capsule:  $\varnothing 8 \times 9 \text{ cm}$   
 Sample:  $\varnothing 7 \times 1.58 \text{ cm}$   
 Al window: 0.2 cm

$^{232}\text{U}$  – 4.1 ppt  
 $^{234}\text{U}$  – 0.0359 wt %  
 $^{235}\text{U}$  – 4.4623 wt %  
 $^{236}\text{U}$  – 0.0068 wt %  
 $^{238}\text{U}$  – 95.495 wt %



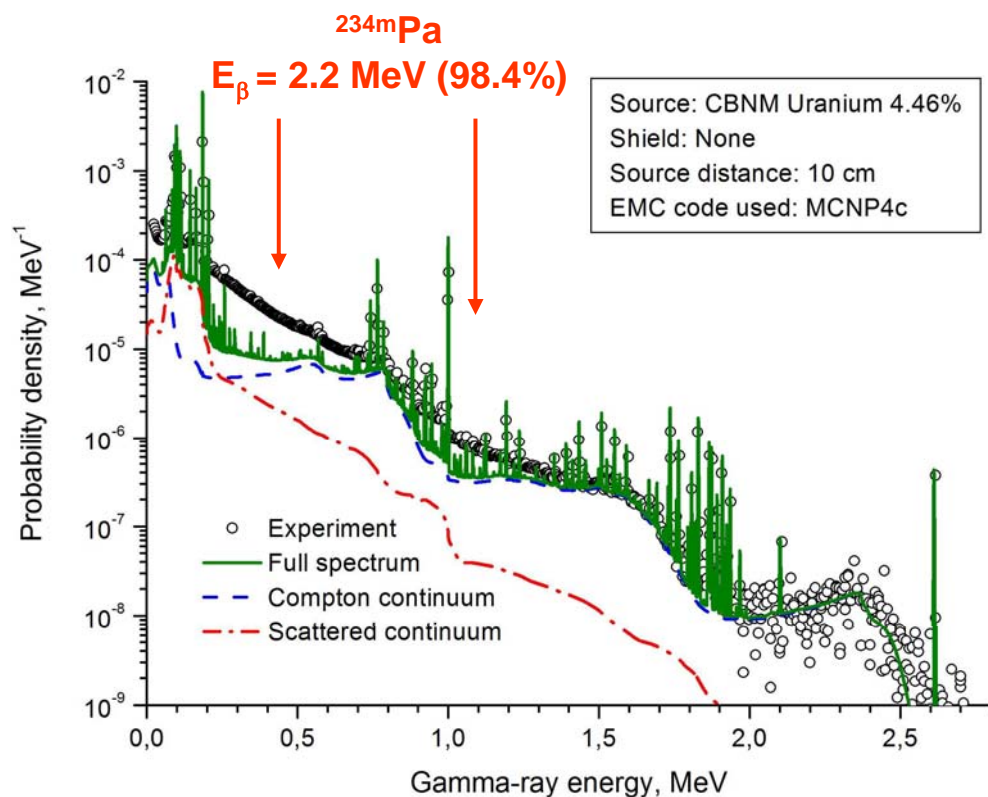
Nuclide	Activity	Nuclide	Activity
$^{234}\text{U}$	14.1 MBq	$^{219}\text{Rn}$	128 Bq
$^{238}\text{U}$	2.02 MBq	$^{211}\text{Pb}$	128 Bq
$^{234\text{m}}\text{Pa}$	2.02 MBq	$^{211}\text{Bi}$	128 Bq
$^{234}\text{Pa}$	3.03 kBq	$^{212}\text{Pb}$	438 Bq
$^{234}\text{Th}$	2.02 MBq	$^{212}\text{Bi}$	438 Bq
$^{235}\text{U}$	607 kBq	$^{224}\text{Ra}$	438 Bq
$^{231}\text{Th}$	607 kBq	$^{208}\text{Tl}$	157 Bq
$^{231}\text{Pa}$	372 kBq	<b>Total</b>	<b>21.4 MBq</b>

## Unshielded CBNM-446: FEP efficiency

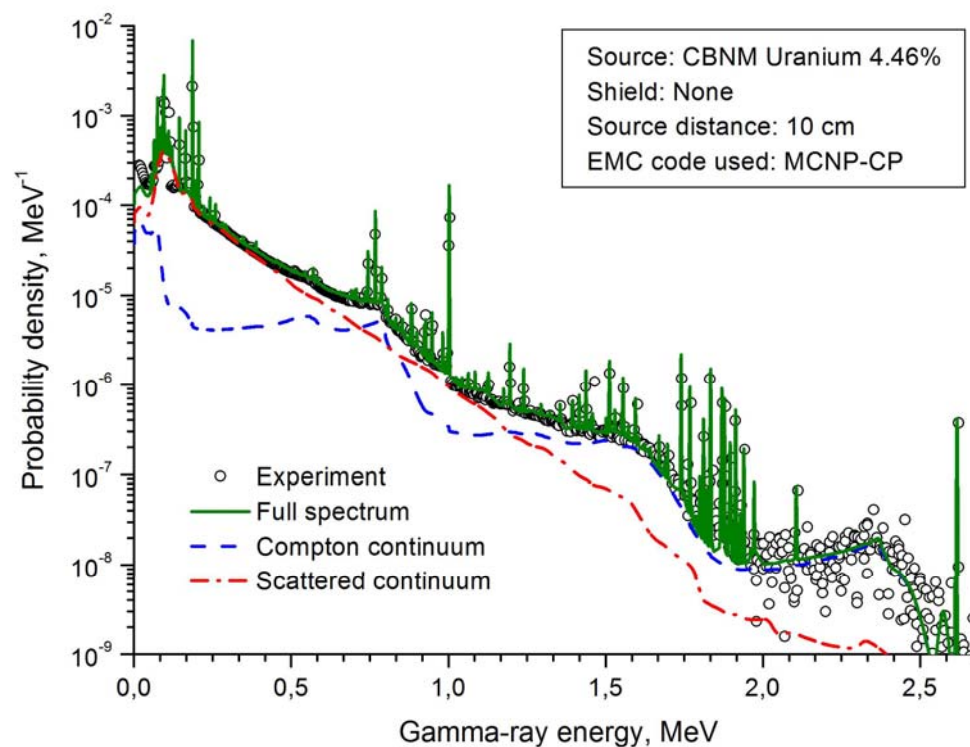


## Unshielded CBNM-446

### EMC option: MCNP4c



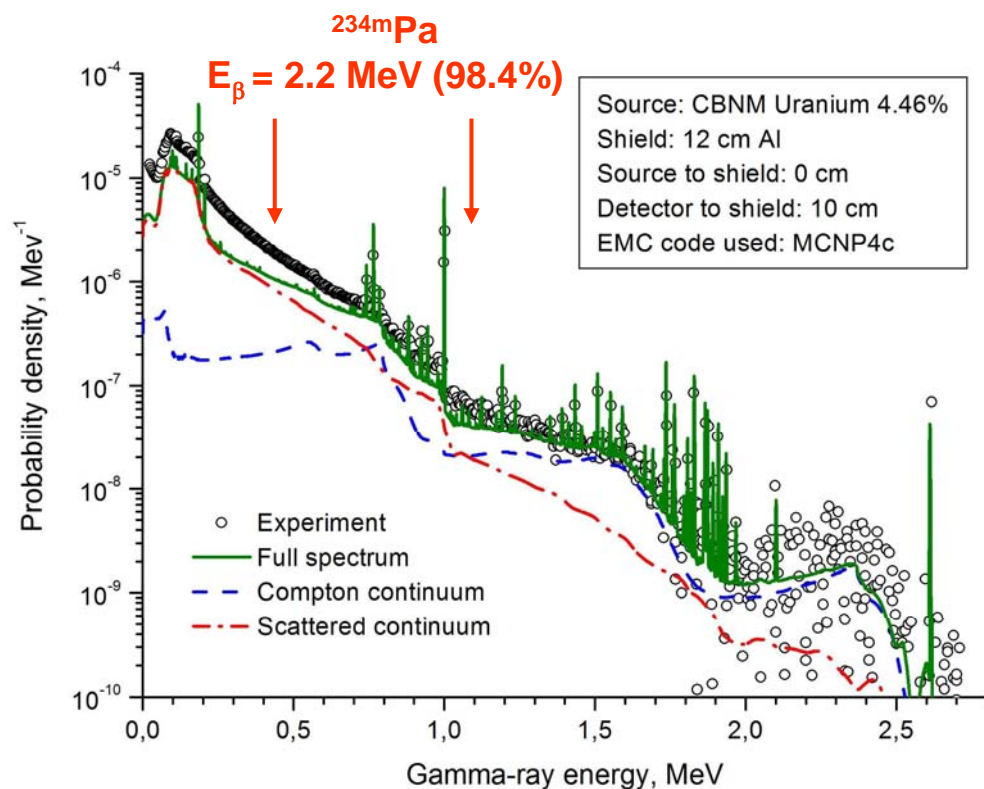
### EMC option: MCNP-CP



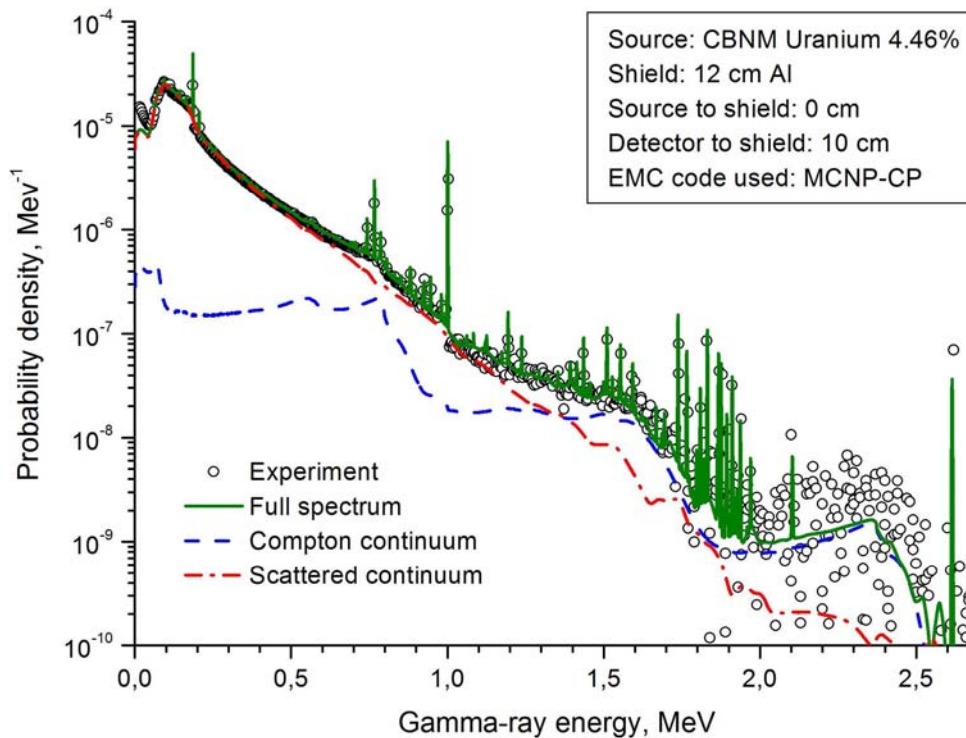


## CBNM-446 shielded with 12 cm Al

### EMC option: MCNP4c

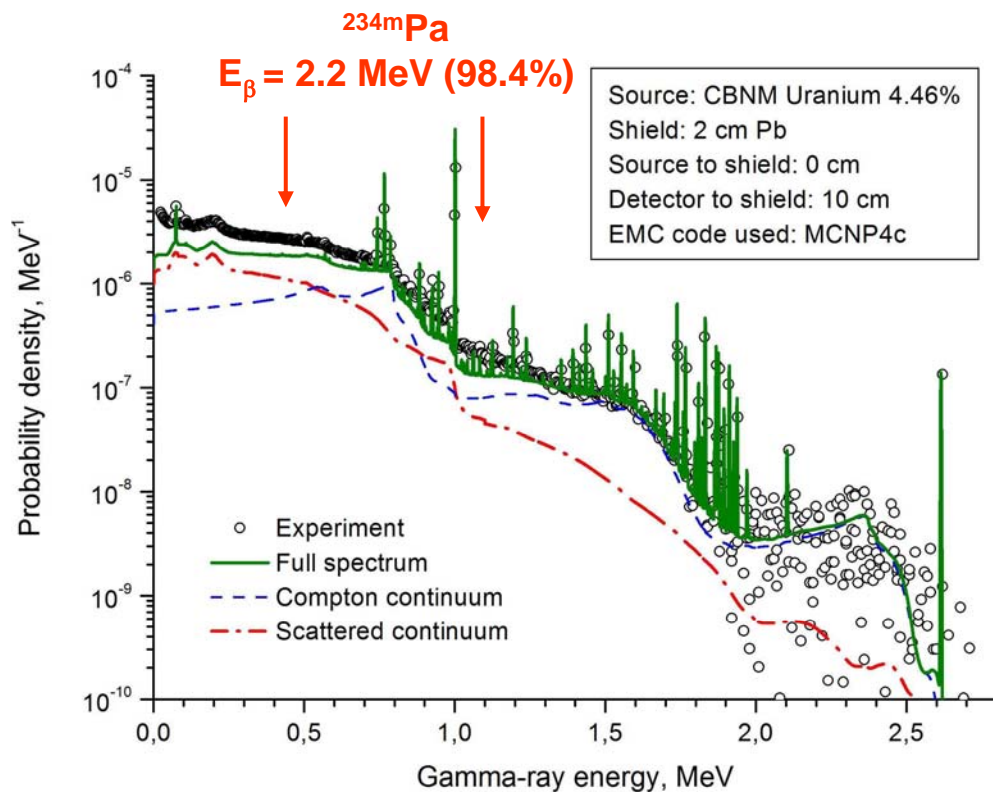


### EMC option: MCNP-CP

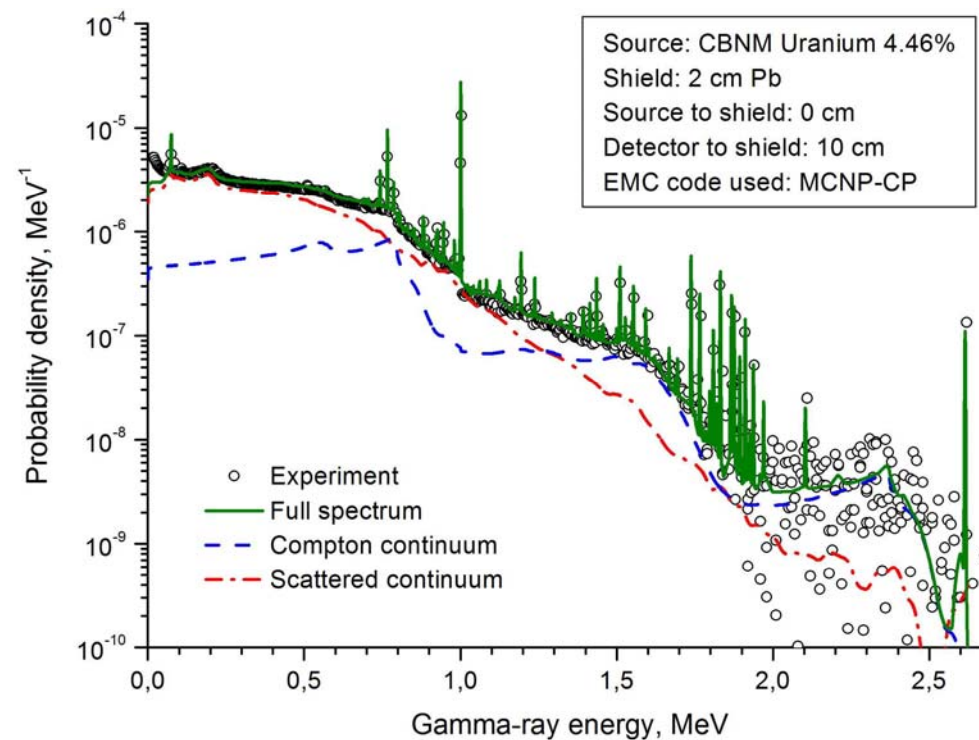


## CBNM-446 shielded with 2 cm Pb

### EMC option: MCNP4c



### EMC option: MCNP-CP

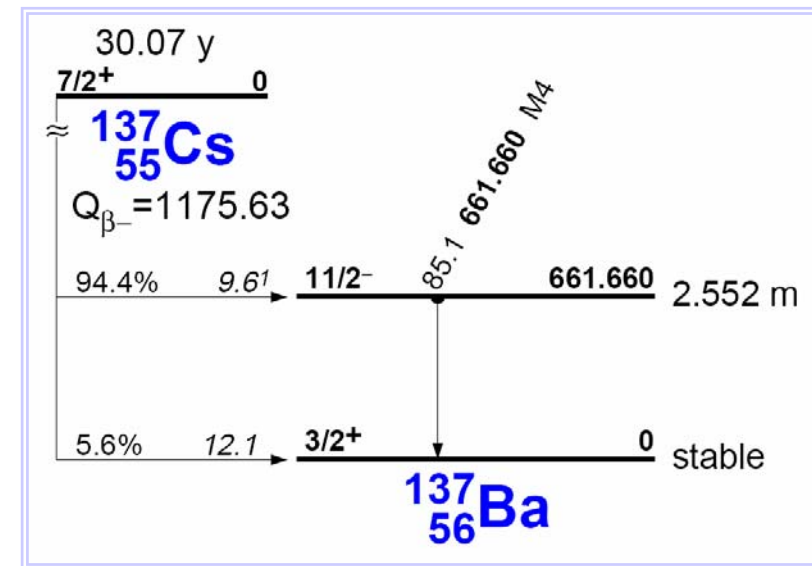
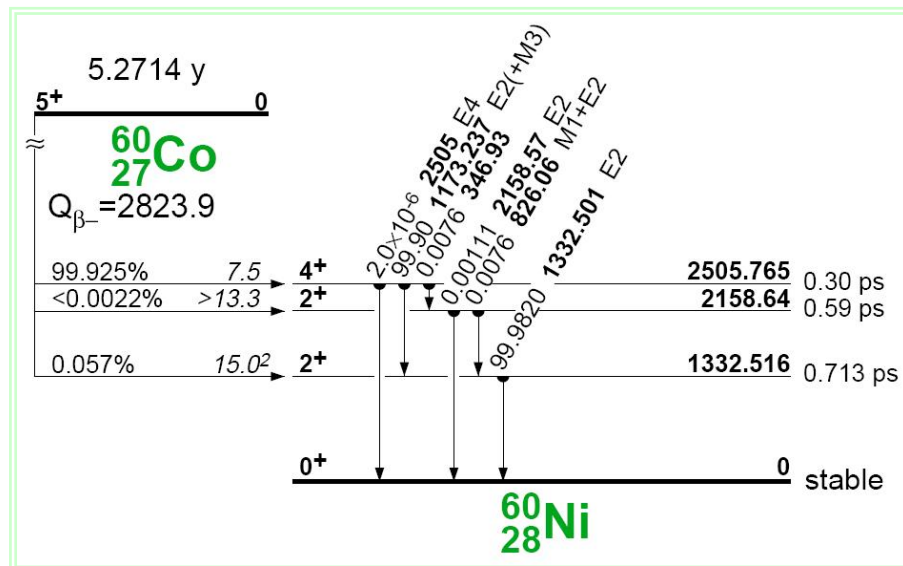




Thanks !



1. The measurement setup is similar to the default configuration “NaI,  $L \times D = 1 \text{ in} \times 2 \text{ in}$  (default)”. You are going to calibrate it using the 1 MBq  $^{60}\text{Co}$  and 1 MBq  $^{137}\text{Cs}$  reference gamma sources. Approximately, how many statistical counts can you expect within 100 s in the corresponding gamma-spectra? Make the evaluations with and without backscattered photon contribution.



**Answer:**  $^{60}\text{Co}$  - without backscatter photons  $\approx 1.66 \cdot 10^5$  and with backscatter photons  $\approx 1.91 \cdot 10^5$  counts,  
 $^{137}\text{Cs}$  - without backscatter photons  $\approx 1.06 \cdot 10^5$  and with backscatter photons  $\approx 1.18 \cdot 10^5$  counts.

2. You have to measure the 10 MBq  $^{152}\text{Eu}$  source with NaI (3"×3") scintillation detector in the measurement setup similar to the default configuration “NaI,  $L \times D = 3 \text{ in} \times 3 \text{ in}$  (default)”. In your disposal there are three lead filters – 1 mm, 3 mm and 5 mm thick. Find the right combinations of the filters, which would make the measurement possible, assuming that your electronics can cope only with input count rates below 20 kcps (kilo counts per second). Check if the same electronics and filters will allow you to perform the measurement in the configuration “HPGe, coaxial, p-type, rel. eff. 150% (default)”.

**Answer: Valid filter combinations: 3 mm + 5 mm (18.8 kcps) and 1 mm + 3 mm + 5 mm (17.2 kcps). The electronics is not suitable for the configuration with 150% HPGe detector since even for the thickest filter combination the predicted input count rate is 22.6 kcps.**

3. What is the relative efficiency of the HPGe detector with crystal length – 30 mm, crystal diameter – 50 mm, rear contact length – 20 mm, rear contact diameter – 10 mm, inactive Ge – 1.5 mm, cap thickness – 1 mm Al, and crystal to cap distance – 5 mm? What crystal length doubles the detector relative efficiency?

**Answer: Relative efficiency = 10.5%. Crystal length  $L = 46.5 \text{ mm}$  gives 21% relative efficiency.**

4. The 1 g natural uranium sample ( $^{234}\text{U}$  – 0.000055 g,  $^{235}\text{U}$  – 0.0072 g,  $^{238}\text{U}$  – 0.992745 g) was measured twice on the same NaI (3"×3") scintillation spectrometer (configuration “NaI, L × D = 3 in × 3 in (default)”). The first and the second measurements were performed for 100000 s respectively 10 days and 1 year after the uranium separation. What are the relative contributions of  $^{235}\text{U}$  and  $^{238}\text{U}$  to the gamma-spectrum measured in both cases? When modeling the spectra, use 1 mm Pb filter to imitate the self-attenuation properties of the sample.

**Answer: After 10 days  $^{235}\text{U}$  - 76% and  $^{238}\text{U}$  - 24%; after 1 year  $^{235}\text{U}$  - 46% and  $^{238}\text{U}$  - 54%.**

5. Based on the gamma-spectrometric examination of a source, the presence of  $^{60}\text{Co}$  with activity 100 kBq was revealed. Which of the default GSG measurement configurations are suitable for detecting an additional presence of 50 Bq of  $^{241}\text{Am}$  in the same source by performing a 1000 s long measurement?

**Answer: Configurations with LEGe and BEGe detectors. The respective MDAs are 12,2 Bq and 18,6 Bq.**